US 12 MP 19.17 Unnamed Tributary to Vance Creek (WDFW ID 125-1806W34G): Final Hydraulic Design Report

Karen Comings, PE, Engineer of Record
David Evans and Associates, Inc., Bellevue, WA, WSDOT Certificate # FPT20-03257

Chad Booth, PE Hydraulic Engineer
David Evans and Associates, Inc. Olympia, WA, WSDOT Certificate # FPT20-27745

Kate Tomlinson, Hydraulic Engineer
David Evans and Associates, Inc. Bellevue, WA, WSDOT Certificate # FPT20-37159

Jeff Parsons, PhD, PE, Geomorphologist
Herrera Environmental Consultants, Inc. Seattle, WA, WSDOT Certificate # FPT20-04847

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

4.2.6 Structure Type 68

Figures

Tables

1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the United States Route (US) 12 crossing of the unnamed tributary to Vance Creek at milepost (MP) 19.17 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 125-1806W34G), and has an estimated 23,937 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure based on unconfined bridge design methodology.

The crossing is located in Grays Harbor County, about 1 mile west of Elma, Washington, in WRIA 22. The highway runs in an east-west direction at this location and is about 100 feet from the confluence with Vance Creek. The unnamed tributary to Vance Creek generally flows from north to south beginning in an agricultural ditch about 1,800 feet upstream of the US 12 crossing. The unnamed tributary to Vance Creek has seasonal flow (see Figure 1 for the vicinity map).

The proposed project will replace the existing twin precast concrete culverts, each 4-foot diameter round and 151 feet long, with a 128-foot-long secant pile bridge designed to accommodate a minimum hydraulic width of 25 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

The original Preliminary Hydraulic Report for this site was completed in 2019 by a different engineering group. The requirements and organization of this document has since changed. This Final Hydraulic Report has updated the preliminary work to the extent practical using provided existing condition information from the earlier work on this site. The preliminary data does not always provide the level of detail that is now expected for fish passage work, and so this report may not contain all the information that is provided in more recent reports.

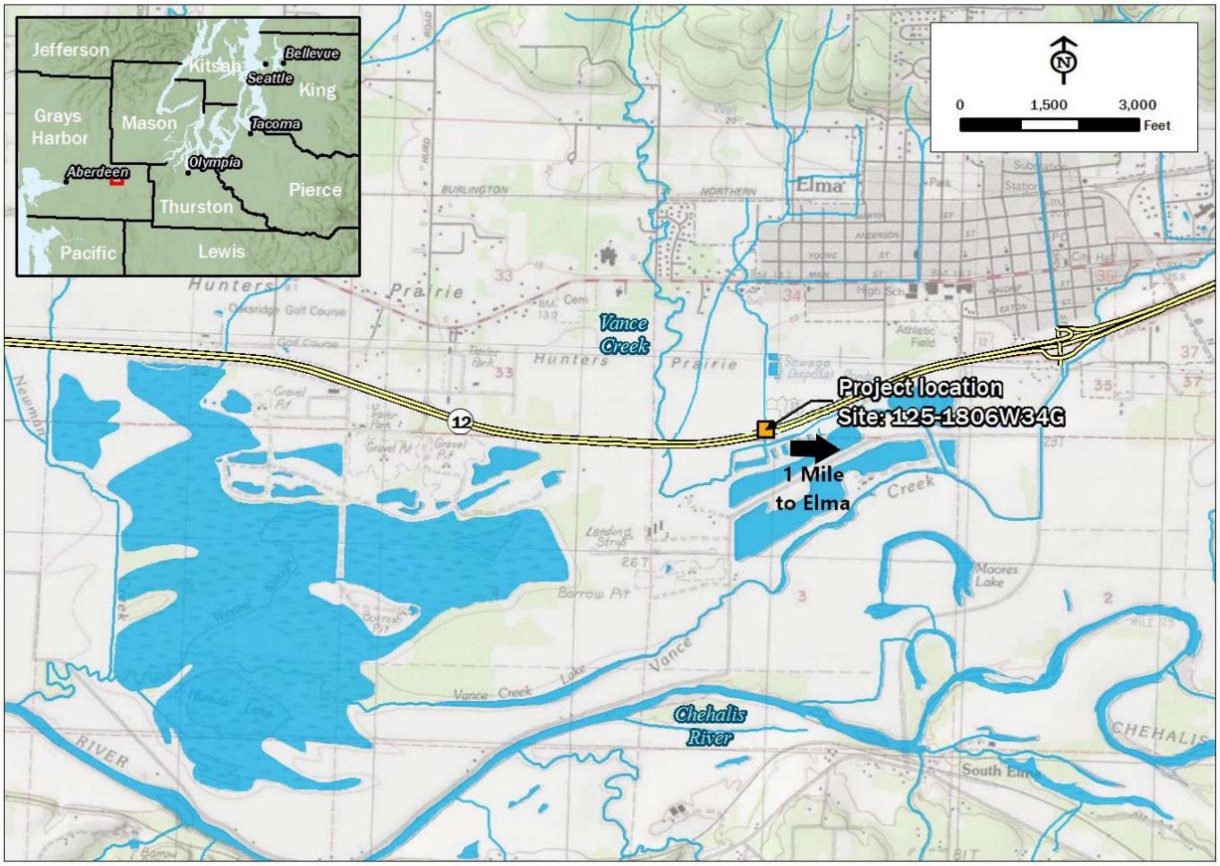


Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

The existing twin precast concrete culvert on US 12 was identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 125-1806W34G) due to insufficient flow depth. The unnamed stream was surveyed by WDFW in April of 2015. They estimated a total potential habitat gain of 23,937 feet upstream of Culvert 125-1806W34G.

The maintenance history of the site was not available at the time of writing.

2.2 Watershed and Land Cover

Figure 2 overview of the watershed that drains into the unnamed tributary to Vance Creek. Land use and cover in the watershed for the unnamed stream is a mix of residential, agriculture, and informal drainage. The headwaters are within the City of Elma. The unnamed stream flows within city limits, passing through residential property. Most of the stream length upstream of US 12 is amid agricultural land use, where it has been redirected to flow along the edges of fields, acting as agricultural drainage. The fields extend to the upstream side of Culvert 125-1806W34G. Downstream of US 12 the land cover is primarily reed canarygrass in flat, ponded areas due to backwater from Vance Creek.

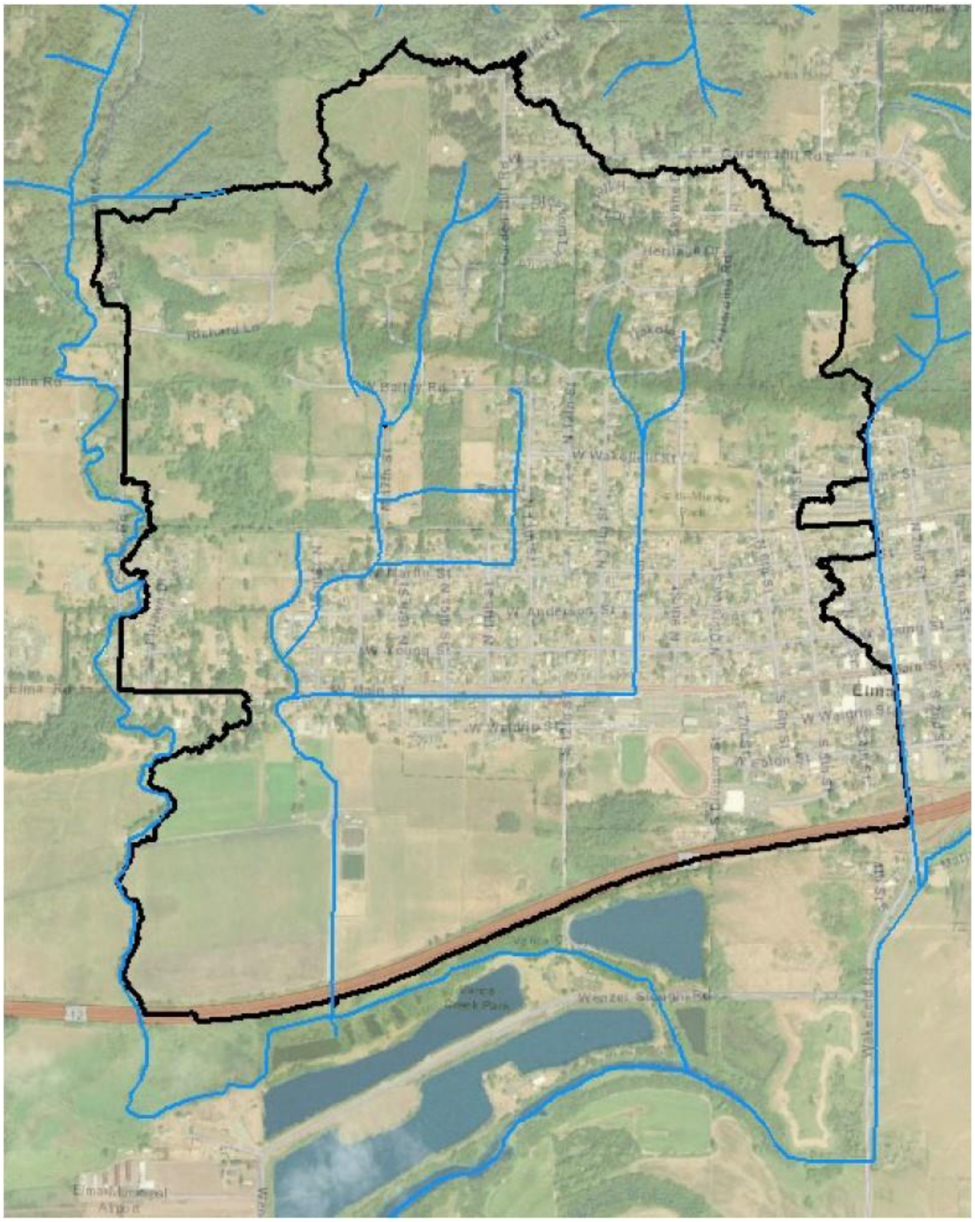


Figure 2. Unnamed Tributary to Vance Creek Watershed Map

2.3 Geology and Soils

The current land surface in the unnamed stream's watershed was created during glacial retreat as Pleistocene Epoch outwash was deposited over Tertiary Period, Miocene Epoch sedimentary rocks. The Miocene rocks are the marine sedimentary rocks of the upper to middle Montesano Formation and are found in higher elevations in Grays Harbor County. They have minimal surface expression in the northeast area of Elma (unit "Mm2" on Figure 3). The surface geology is predominantly of the Pleistocene Epoch, having been deposited either before or during the Fraser Stade. The headwaters of the unnamed stream flow through pre-Fraser age continental glacial drift, unit "Qgp" on Figure 3, consisting of outwash sands and gravels. These pre-Vashon age sands and gravels outcrop to form a terrace on the north side of the Chehalis Valley through which the unnamed stream flows.

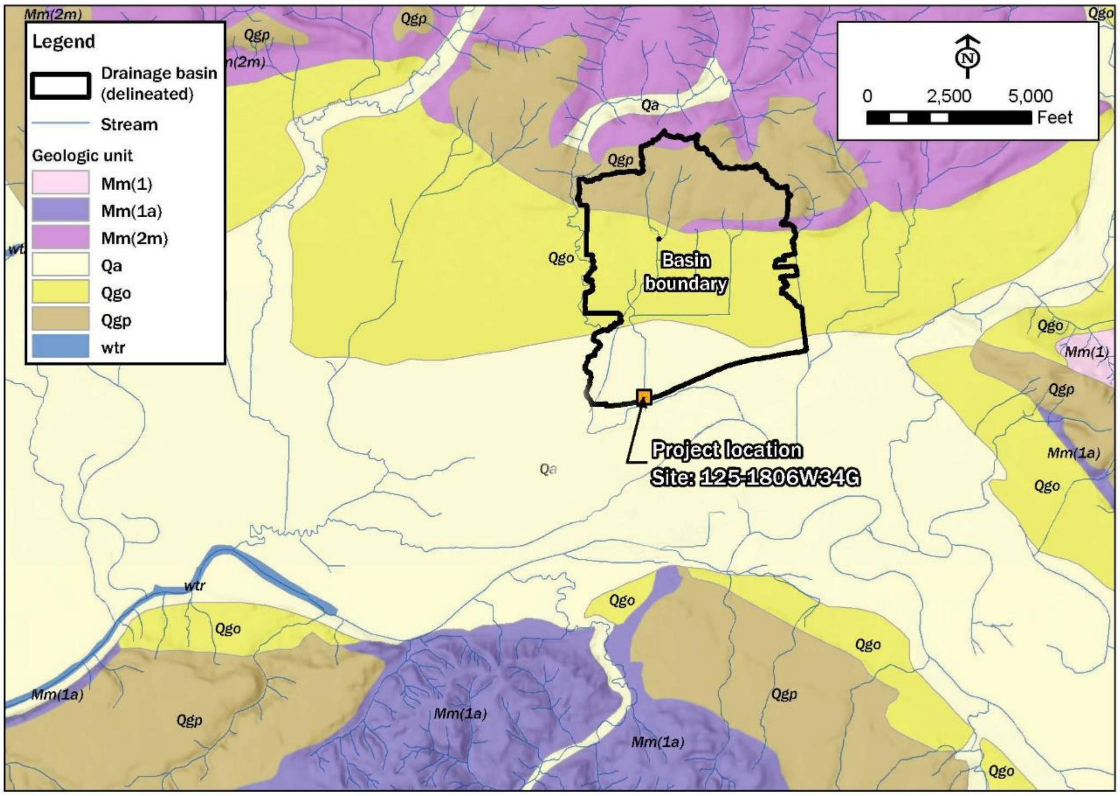


Figure 3: Geologic map

The surficial geology where the upper portion of the stream passes through the city of Elma is mapped as Fraser age continental glacial outwash, primarily of the Vashon Stade. This is proglacial and recessional outwash deposited during the Pleistocene Epoch. The gravels in this area are rounded and moderately sorted with a large component of sand and fine-grained materials. Within the area marked by the 1 percent annual chance flood hazard, as discussed in Section 2.7.2.1, corresponding to most of the agricultural land, the surface is undifferentiated Quaternary age alluvium, labeled as unit “Qa” on Figure 3.

Area soils reflect this glacial history and are distinguished by moderate to high infiltration rates. In the upstream reaches of the drainage basin, the soils consist of Centralia loams and Buckpeak and Montesa silt loams of the steeper Rony-Gate complex (see Figure 4 and Table 1). There is relatively significant topographic relief in the headwaters, and these soils are typical of stream terrace deposits and slopes up to 65 percent. The higher elevation terrace location coincides with the city of Elma residential areas where the unnamed stream flows over the Miocene age terrace rocks and pre-Fraser glacial deposits. The infiltration rates range from low to moderately high. Where the unnamed stream passes through agricultural fields between Elma city limits and US 12, the soils are Satsop silt loams of the Delezene-Rony complex. This complex is considered prime agricultural soil with a consistent silt loam to a depth of 60 inches below the ground surface. Ground surface slopes are low in this soil, and infiltration rates range to moderately high. Soils immediately upstream of the US 12 culvert are of the Carstairs series, which is characterized by very gravel loam and gravelly loam. These are low gradient soils found at 0 to 5 percent slopes. They extend to over 30 inches depth. The infiltration capacity is rated as moderately high to high, making these good agricultural soils. All the mapped soils in the watershed areas upstream of US 12 are associated with moderate to high infiltration rates. Combined with the flat land surface near US 12, these soils create a condition where the unnamed stream channel is frequently dry upstream of the highway. Soils information is from the NRCS and downloaded from the Grays Harbor County website.

In the immediate vicinity of the culvert crossing of US 12, the soils are mapped as Montesa silt loam to Nemah silty clay loam (see Figure 4 and Table 1). The increase in clay content in these soils creates a condition of lesser infiltration and water ponding, which is likely contributing to ponding that is prevalent between the outlet of Culvert 125-1806W34G and the confluence with Vance Creek. Downstream of the confluence, Vance Creek flows through the Carstairs very gravel loam and gravelly loam. The high infiltration capacity of these soils allows for active interflow between the ponds and Vance Creek.

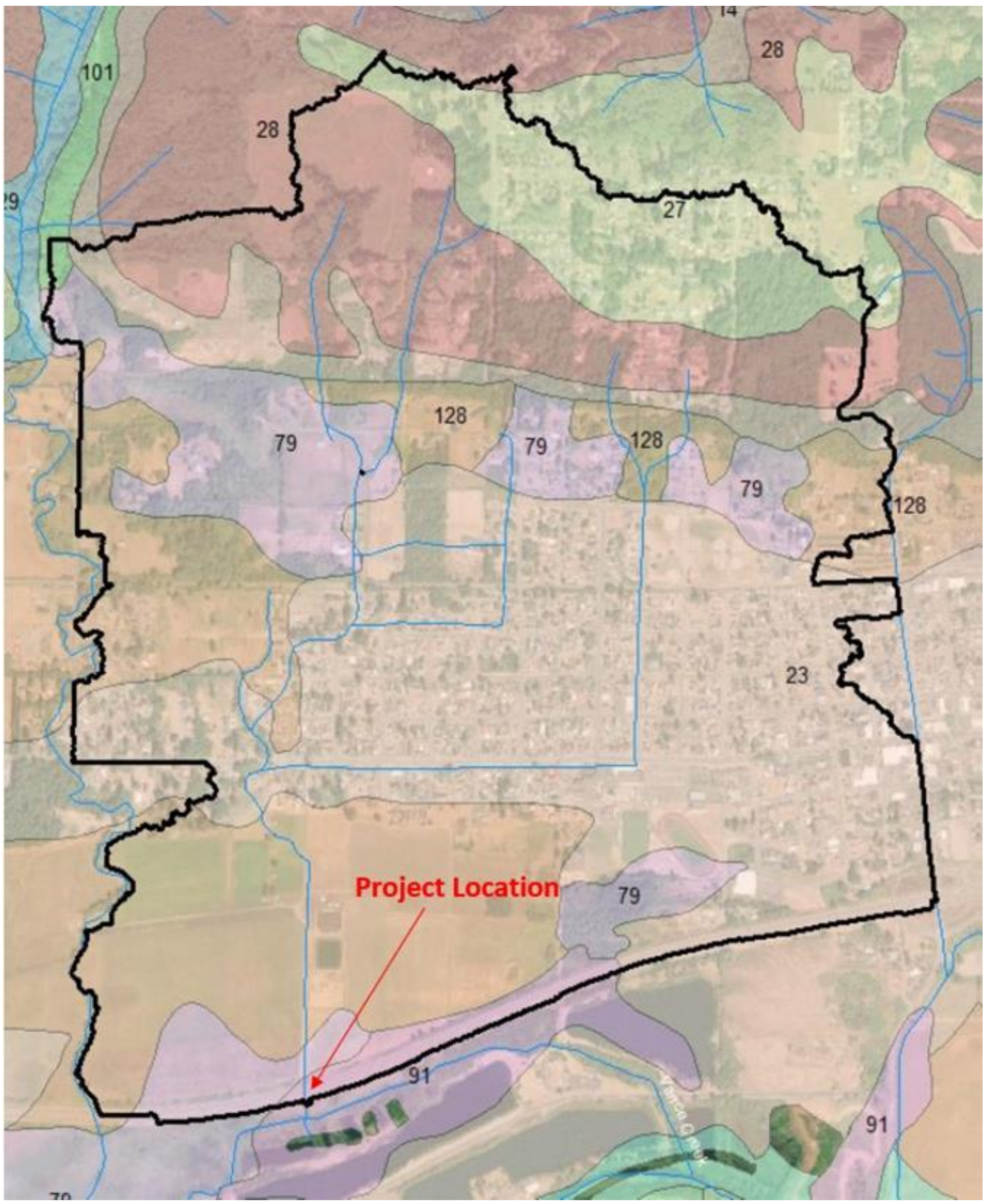


Figure 4: Soils map

Table 1: Soils in the drainage basin of the unnamed tributary to Vance Creek

Map Unit Symbol (See Figure 4)	Soil Unit Name	Slope (percent)	Hydrologic Soil Group
27	Centralia Loam	1-8	B
28	Centralia Loam	8-30	B
14	Buckpeak Silt Loam	30-65	B
128	Satsop Silt Loam	1-8	B
79	Montesa Silt Loam	1-8	C
23	Carstairs Very Gravelly Loam	1-8	A
91	Nemah Silty Clay Loam	0	B

2.4 Fish Presence in the Project Area

Table 2 provides a list of native fish found within the unnamed stream. Coho fry were directly observed by the WDFW in the April 2015 physical survey. Coho smolts, cutthroat trout, and rainbow trout were observed with less certainty during the same site visit.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho salmon (Oncorhynchus kisutch)	Documented	Physical Survey (WDFW)	Not Warranted
Coastal cutthroat trout (Oncorhynchus clarkii)	Documented	Physical Survey (WDFW)	Not Warranted
Resident rainbow trout (Oncorhynchus mykiss)	Documented	Physical Survey (WDFW)	Not Warranted

2.5 Wildlife Connectivity

The 1-mile-long segment that US 12 MP 19.17 falls in is ranked high priority for Ecological Stewardship and medium priority for Wildlife-related Safety by WSDOT Headquarters (HQ) ESO. Adjacent segments to the west and east ranked high and low respectively for Ecological Stewardship, and medium for Wildlife-related Safety.

WSDOT ESO recommended a structure with a minimum 10-foot vertical clearance and 20-foot horizontal width with a 5-foot wide bank. An openness ratio of 2.0 is also recommended. The proposed secant pile bridge design has a vertical clearance of approximately 23 feet and a horizontal width of 25 feet. The design has 6.5-foot channel benches on either side of the channel and an openness ratio of approximately 4.3. Therefore, the wildlife conductivity recommendations have been accommodated.

2.6 Site Assessment

This section discusses the current conditions of the crossing and immediate vicinity.

2.6.1 Data Collection

The site assessment was performed primarily over two site visits. On August 6, 2019, the upstream area was investigated. On August 23, 2019, the downstream reach to the confluence with Vance Creek was visited. Both site visits included walking the stream channel and immediate area around it while taking measurements pertinent to the geomorphic and habitat analyses.

Survey data was also conducted in August of 2019. The survey along the unnamed tributary to Vance Creek extended approximately 200 feet upstream and downstream of the existing culvert and includes the confluence with Vance Creek downstream of the culvert. Survey data was also collected along the Vance Creek mainstem extending approximately 200 feet upstream and downstream of the confluence.

Three bankfull width measurements, shown as sites 1, 2, and 3 in Figure 5, were collected and are discussed in detail in Section 2.7.2. No pebble counts were conducted for this project due to the fine nature of existing sediment, as explained in Section 2.7.3.

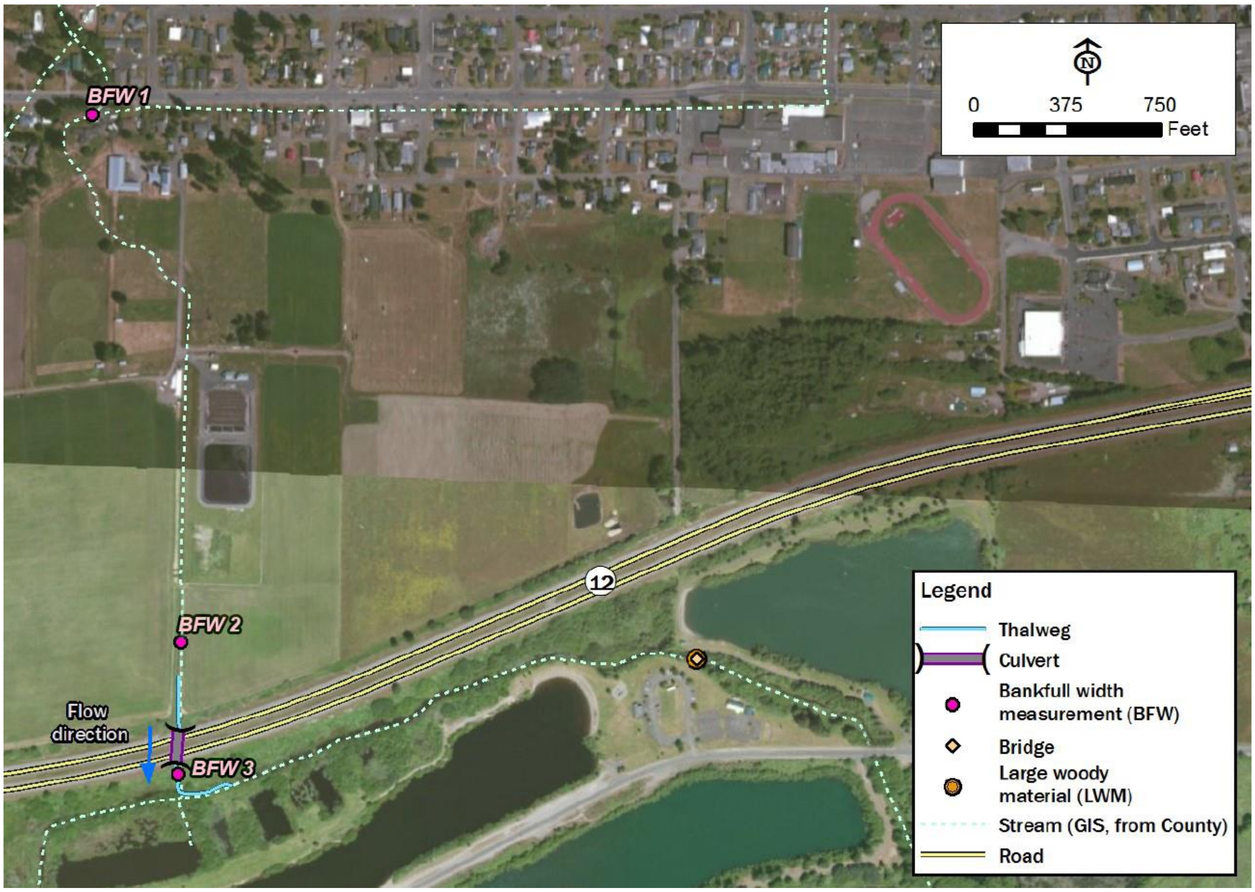


Figure 5: Unnamed stream alignment with locations of channel measurements

2.6.2 Existing Conditions

The unnamed stream channel was dry in the agricultural ditch reach immediately upstream of Culvert 125-1806W34G. The flow path is between two agricultural fields that are in active cultivation (see Figure 6). At the time of the site visit on August 6, 2019, the majority of the reach was dry, and water was encountered only immediately upstream of the culvert. There is a second culvert approximately 500 feet upstream of Culvert 125-1806W34G. It is a rusted 36-inch-diameter corrugated metal pipe that appears to function to convey water under an earthen road between fields.

Figure 6: Unnamed tributary to Vance Creek upstream of Culvert 125-1806W34G

Further upstream the unnamed stream passes through Elma. Approximately 3,000 ft upstream of Culvert 125-1806W34G, the stream passes through a 5.5-foot-diameter culvert under Main Street. High flow marks on the upstream side of this culvert indicate relatively recent flows reached 17 feet wide and 8 feet deep. Downstream of this culvert the stream flows through a cultivated lawn that shows sign of being overtopped and eroding during high flows (see Figure 7). The channel banks have been hardened where the stream passes through residential yards. There was no water in the stream in this area during the site visit on August 23, 2019.

Culvert 125-1806W34G consists of two 4-foot diameter 151-foot-long round concrete culverts at a 0.39 percent slope with matching invert elevations at the inlet and outlet. Figure 8 shows the culvert inlet and Figure 9 shows the culvert outlet. The culvert outlet was hanging above the channel bed with the elevation of the outlet invert approximately 1 foot above the water surface during the site visit in August 2019. The stream channel begins to widen where the banks have collapsed immediately downstream of the culvert (see Figure 9). The unnamed stream flows through a ponded wetland area for 100 feet to its confluence with Vance Creek. Vance Creek continues through Vance Creek County Park, under a footbridge, and through a flat area in the Chehalis River floodplain, passing through three culverts under Wenzel Slough Road over a length of approximately 3 miles before its confluence with the river. During the site visit on

August 6, 2019, water was present in the downstream reach of the unnamed stream, between US 12 and the Vance Creek confluence, but was not noticeably flowing (see Figure 9).

Several beaver dams exist along Vance Creek within the county park area, particularly in the area of the footbridge. The beavers have been removed, but the dams remain in place. These dams impact the flow of Vance Creek and contribute to a backwater condition in the unnamed stream downstream of Culvert 125-1806W34G. There are several large ponds adjacent to Vance Creek. Conversation with the park superintendent informed the site visit findings. The area around the ponds often floods, but the water does not overtop US 12 or into the agricultural fields upstream of the culvert. The first culvert that Vance Creek flows through under Wenzel Slough Road at the south edge of the county park is a double box culvert, 10 feet wide, and 7.25 feet high. One opening is free of debris while the second has accumulated approximately 1.5 feet of debris (broken concrete, wood) spread across the width of the culvert. There is concrete rubble at the inlet and outlet of this culvert. Additional ponds to the south of Wenzel Slough Road near the county park are privately owned.

Figure 7: Unnamed tributary to Vance Creek passing through a yard in Elma

Figure 8: Inlet to Culvert 125-1806W34G

Figure 9: Outlet of Culvert 125-1806W34G.

2.6.3 Fish Habitat Character and Quality

Fish presence and use of the unnamed stream was documented in the April 2015 WDFW physical survey of the site. However, site investigations in June and August 2019 encountered a dry channel that prevents fish use in the summer months. The stream would likely be used for non-natal rearing during the fall and winter prior to outmigration in the spring for coho salmon, and for non-natal rearing and refuge during fall, winter and spring for coastal cutthroat and resident rainbow trout. The unnamed stream currently offers poor quality non-natal rearing habitat for salmonids with minimal instream habitat complexity, prolonged lack of flow, and a lack of overhanging riparian vegetation.

The existing crossing under US 12 is a partial barrier to fish passage due to shallow depth, even during higher flow events. The culvert consists of two 4-foot-diameter pipes spaced 4 feet apart, formed in precast concrete. The concrete aprons on either end are approximately 6.6 feet long and 16.4 feet wide. The channel upstream of the culvert shows some evidence of scour leading up to the apron with broken concrete, riprap, and quarry spalls placed at the toe of the apron. The bottom of the downstream end of the culvert was coincident with the water level in the downstream channel during the site visits. The stream was flowing very slowly, nearly without apparent downstream velocity, during the June and August site investigations.

The upstream channel consists of a straight, narrow, channelized ditch that runs between adjacent agricultural fields. The downstream channel confluences with Vance Creek approximately 100 feet from the Culvert 125-1806W34G outlet. There is a barbed-wire fence that runs perpendicular to the unnamed stream, approximately 30 feet from the Culvert 125-1806W34G outlet. Fish presence upstream of the culvert is extremely unlikely during the dry summer months when flow is absent or diminished in the unnamed stream.

Although the habitat quality in the reach immediately upstream of Culvert 125-1806W34G is poor, reaches farther upstream include increased riffles, gradient, riparian vegetation and canopy cover, and gravel surface substrate. This improved habitat can only be accessed after passing upstream through approximately 0.5 mile of poor-quality habitat consisting of low gradient (0.007 percent) pooled ditches along roads and through pastures and agricultural fields. In this 0.5-mile reach, there is no LWM, minimal riparian vegetation composed almost exclusively of nonnative invasive species, and no canopy cover. The substrate is composed almost exclusively of sands and fines.

Downstream of Culvert 125-1806W34G, the stream habitat quality is fair to good. The confluence of the unnamed stream with Vance Creek is within a low gradient (0.004 percent) wetland complex. Some LWM is present in Vance Creek, often in relation to abandoned beaver dams or collected at the inlet to downstream culverts. The streambed is composed of 100 percent fine sediments and has a mix of native and nonnative emergent and wetland riparian vegetation. Some canopy cover is provided by deciduous trees that line Vance Creek through Vance Creek County Park.

The unnamed stream was surveyed by WDFW in April of 2015. They measured a total potential habitat gain of 23,937 feet upstream of Culvert 125-1806W34G. While this is an incremental gain in a habitat that is likely unsuitable for rearing salmonids, enabling fish passage at the US 12 crossing could enhance flow in downstream reaches and provide refuge areas for fish during high flow events in Vance Creek. The upstream reach is 100 percent riffle over the 500 linear feet investigated; the downstream reach is 100 percent glide over the 300 feet surveyed. While none of the habitat would be used for spawning by salmonids due to the lack of suitable gravel substrate, access to stream reaches farther upstream would extend the amount of non-natal rearing habitat.

There are 28 road crossings of Vance Creek and the unnamed tributary. Of the 10 crossings located upstream of Culvert 125-1806W34G on the unnamed stream, 7 of them are partial barriers; and it is unknown whether 2 of them are passable (they have not been assessed). There are no crossings downstream of Culvert 125-1806W34G on the unnamed stream.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

There are no pieces of large woody material (LWM) and no trees to provide future LWM to the reach for 0.5 mile upstream of Culvert 125-1806W34G. The unnamed stream flows through several agricultural fields and pastures where the riparian vegetation is limited to cultivated and nonnative species. The first trees encountered in the stream corridor upstream of US 12 are along private properties located south of West Main Street in Elma, but these are unlikely to be a notable source of downstream LWM as farmers and ranchers would likely remove any accumulations of wood in the stream channel that could hinder drainage of agricultural fields. Reed canarygrass growth is extensive throughout this upstream reach. Additional invasive species observed along the reach include tansy ragwort, bindweed, and Himalayan blackberry.

Downstream of Culvert 125-1806W34G, there are several pieces of LWM within Vance Creek, mostly associated with the now abandoned beaver dams discussed in Section 2.6.2 or collected at inlets to downstream culverts. The potential for LWM recruitment is much greater in the reach of the unnamed stream between US 12 and the confluence with Vance Creek. At the confluence of the unnamed stream with Vance Creek, the habitat is a wetland complex with the right bank lined with deciduous trees, such as willow (Salix spp.) and poplar trees (Populus spp.).

Groundwater expressing at the ground surface was not evident on the upstream side of Culvert 125-1806W34G during the field work conducted in June and August 2019. Downstream of the culvert, the groundwater table is likely coincident with the water surface elevation in Vance Creek and would therefore be similar to the elevation in the 100-foot-long reach of the unnamed stream between Culvert 125-1806W34G and the confluence with Vance Creek. Water in the former mining pits south of US 12 illustrates the elevation of the groundwater table. The groundwater is not expected to be impacted by the project, but the proximity of the groundwater table will likely influence project construction.

Near the confluence of the unnamed stream and Vance Creek, the area was converted from gravel pits and agricultural area to what is now Vance Creek County Park. This 140-acre park is used for fishing, swimming, and nature hikes. There have been no other documented improvements to fish passage in the Vance Creek watershed

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of the unnamed tributary to Vance Creek.

2.7.1 Reference Reach Selection

As will be discussed in Section 2.7.2, the full length of the unnamed stream channel has been manipulated. There is not a reach upstream or downstream of the US 12 crossing that can be considered in a natural condition. So, no reference reach was selected.

Creeks in the area nearby the project location were considered (see Figure 10). The region is a terraced floodplain of the Chehalis River with residential areas (like Elma) on the terrace elevation with the floodplain area in agriculture. The creeks, for example the tributary to MacDonald Creek immediately east and Wenzel Slough to the west, are similar to the unnamed tributary in the level of manipulation. We considered Vance Creek as a surrogate, however, its drainage basin is much larger and drains a greater diversity of soil types so the geomorphology of the Vance Creek system would not present an analogue. Further to the east or west the soils and geology in the drainage basins differ enough in their hydrologic soil group characteristics from the project location to make them unsuitable for use as a reference for the natural condition of the unnamed tributary to Vance Creek.

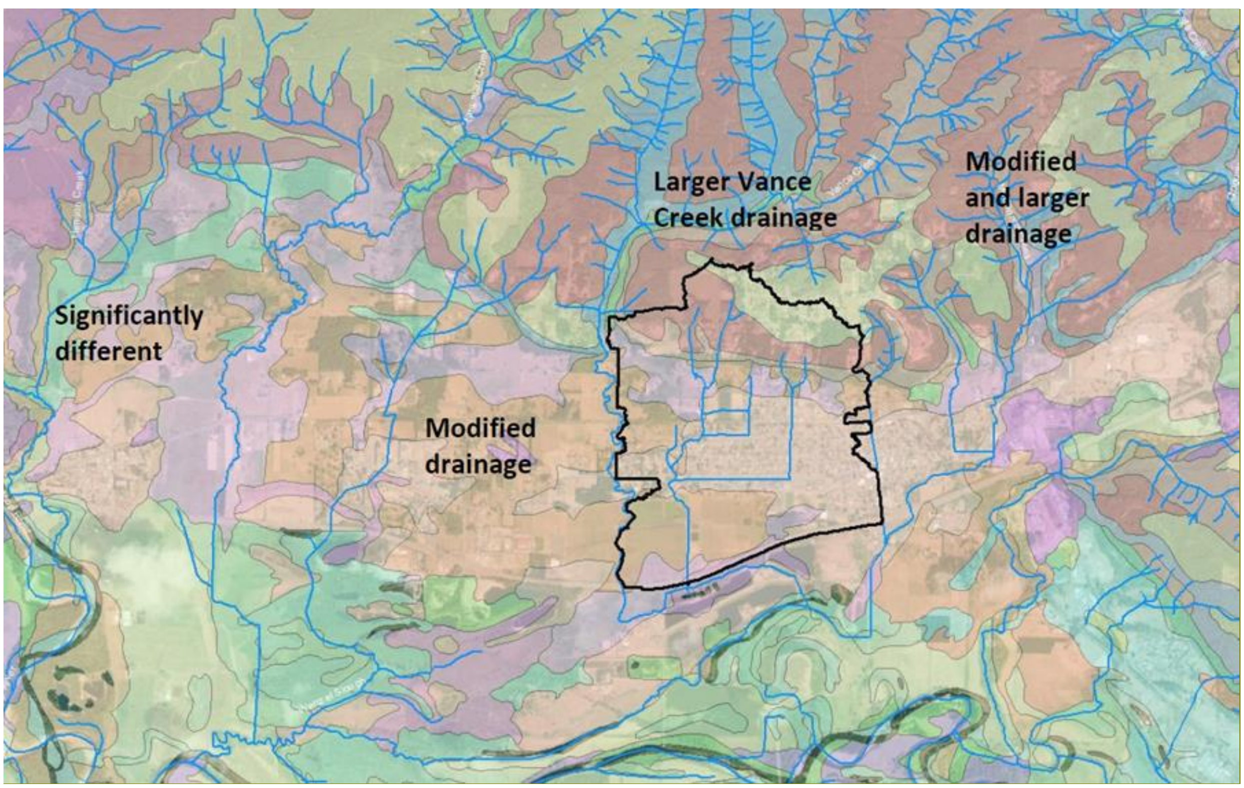


Figure 10: Extended area around project location with drainage basin to Culvert 125-1806W34G outlined.

2.7.2 Channel Geometry

The unnamed tributary to Vance Creek has been modified in relation to human uses of the land throughout its course. The degree of modification ranges from moderate manipulation in the uppermost reaches to fully channelized and ditched in the agricultural fields immediately upstream of Culvert 125-1806W34G. The moderately altered sections have hardened banks and are over 3,000 feet upstream of Culvert 125-1806W34G, upstream of most of the drainage contributions from Elma and the agricultural fields. Channel reaches as far upstream as Elma are on a historical floodplain terrace deposit where the 6 percent slope is much higher than the 0.5 percent slope in the agricultural fields downstream and near US 12. Because of the slope difference, these upstream reaches have a different geomorphic character than is seen in the stream channel near the US 12 crossing. In between, the channel flows between agricultural fields as a drainage ditch for 2,500 feet before reaching the US 12 culvert entrance.

The reach downstream of Culvert 125-1806W34G observed during the site inspection is distinguished by eroded bank areas, wetland conditions, and backwater from Vance Creek and the Chehalis River. The confluence with Vance Creek is only 100 feet downstream of Culvert 125-1806W34G and is in the immediate vicinity of numerous large ponds that were once quarry pits (see Figure 5). Vance Creek is also highly modified and channelized with significant beaver activity contributing to a low hydraulic gradient and backwater that extends up to the invert of Culvert 125-1806W34G.

Channel cross-section geometry, including bankfull width, was assessed and measured at three locations (see Figure 5). However, only two sites provided relevant results (see Table 3). BFW-1 is far to the north at the culvert crossing Main Street in Elma. On the upstream side of the Main Street culvert the channel was highly incised. The area around it was overgrown with invasive species where the stream passes between two residences. The channel maximum width at the top of the culvert was 17 feet and bank height approximately 4 feet. On the downstream side of the Main Street Culvert, the channel banks have been reinforced and yard drains added (see Figure 7). The creek overflows its banks and there is visible evidence of yard erosion around the large bank protection rocks. The channel top width was measured at 13 feet and the bank height approximately 4.5 feet, but the measurements were to the extents of the erosion (where the pipe extends from the yard). The channel top width and bank height are not considered bankfull measurements at BFW-1 because the channel is actively eroding and not representative of a stable channel.

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?
1	N/A	N/A
2	8.6	No
3	12	Yes
Design BFW	**12**	

BFW-2 is 250 feet upstream of Culvert 125-1806W34G and halfway to the upstream secondary agricultural culvert. The channel is an agricultural ditch approximately 2.4 feet deep at this location. The inset channel is 8.6 feet wide but the larger channel width that may be filled during flow events is approximately 12 feet. Figure 6 shows the measured inset channel bankfull width at this site. The lack of flowing water or high-water marks drove the decision to measure bankfull width at the inset channel. Cross section near BFW-2 is provided in Figure 11.

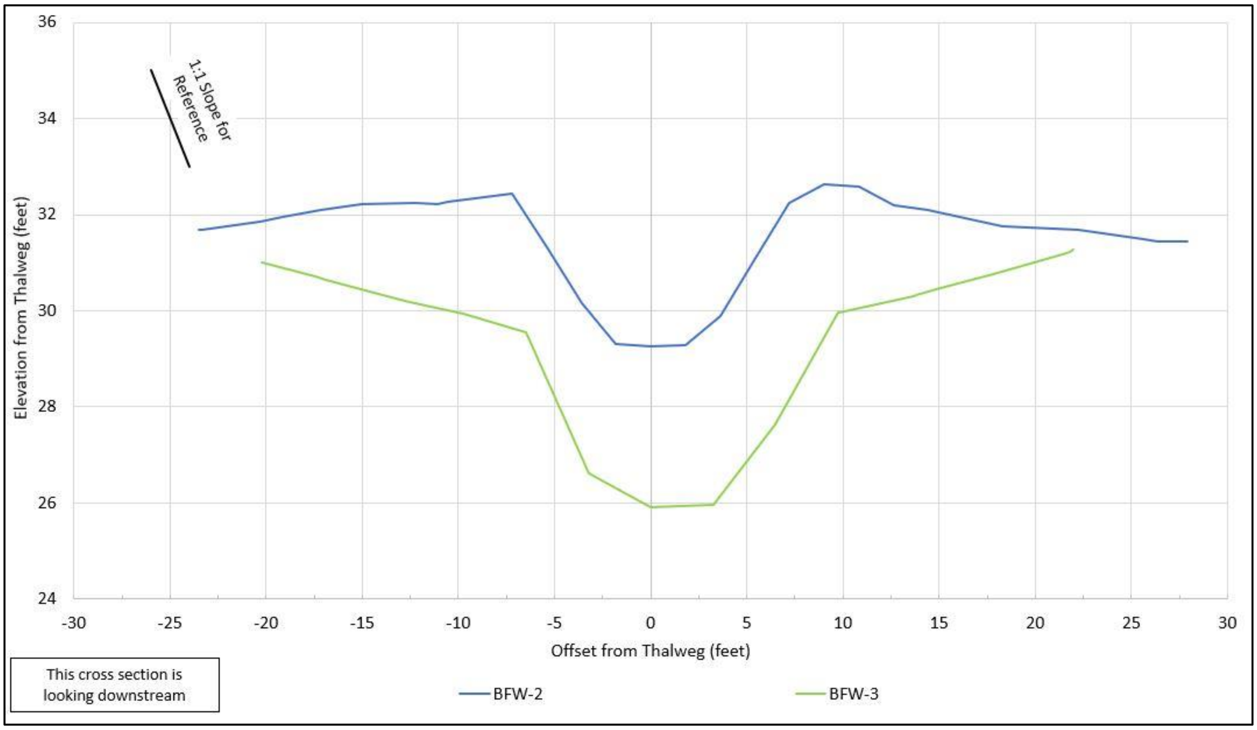


Figure 11: Existing cross-section example

The channel reach downstream of US 12 is approximately 12 feet wide on average (BFW-3). The banks of the channel are overgrown with reed canarygrass that is overhanging the channel. The banks on both sides have eroded areas such that although the banks are vertically straight, there has been erosion that locally widens the channel by a foot. This type of bank erosion is more common where the channel has slow increases and decreases in water elevation, as occurs with backwater from a larger river confluence immediately downstream. The channel was deeper than we were able to measure at this location. The elevation of the hanging culvert was determined from the survey to be 3 feet over the channel bed (see Figure 9).

The manipulated nature of the channel made defining a representative bankfull width that could be considered to approximate a natural condition impossible. There are no adjacent basins that could be used to provide a representative reference reach. However, our inspection revealed several hydraulic and geomorphic indicators that could be used to reasonably estimate channel and bankfull width suitable as a basis for design of the new US 12 crossing. First, there was an overall similarity of channel width upstream and downstream of Culvert 125-1806W34G. The upstream channel width appears to contain flood flows and was estimated to be 12 feet with an inset bankfull width approximation of 8.6 feet (see Figure 11). The channel downstream of Culvert 125-1806W34G did not have any direct bankfull width indicators, but due to its backwatered hydraulic connection to the confluence with Vance Creek, the channel width that appears to convey flood flows was also estimated to be 12 feet. Secondly, the culvert does not show any signs of impeding flow. Its perched state at the downstream end indicates the unimpeded conveyance of upland drainage in the stream, and reduced potential for backwater into the culvert.

Downstream of US 12 the channel is equally modified. Over the short distance to the confluence with Vance Creek the unnamed tributary is a backwater channel and wetland area. Therefore, as applicable to assessing fish passage, we estimate the appropriate bankfull width is 12 feet.

2.7.2.1 Floodplain Utilization Ratio

The Preliminary Hydraulic Design (PHD) report did not include FUR measurements at individual sections along the stream, and instead estimated one FUR for the entire area.

The unnamed stream channel visually appeared to be confined during the site visits, but the simulated 100-year flood flow inundation width upstream of Culvert 125-1806W34G is very large due to the varying backwater effects from the Chehalis River, as seen in Figure 12. Even without backwater from the Chehalis River, the 100-year floodplain is very wide. The corresponding FUR, when considered with or without backwater scenarios, is very large defining the channel as unconfined at the US 12 crossing.

Figure 12: FEMA floodplain map for the unnamed stream and Vance Creek. Brown shading indicates 0.2 percent chance annual flood hazard and teal shading indicates 1 percent chance annual flood hazard.

2.7.3 *Sediment*

The channel bed surface and structure were evaluated visually throughout the project reach. The channel bed was consistently composed of a mix of organics and very fine silts, sands, and clays. The organic layer was thickest at Site 3 where layers of reed canarygrass were decomposed on the surface. There were no gravels observed at any point in the system, thus there were no locations where a pebble count was possible. This is an intermittently flowing stream with a very fine sediment bed.

2.7.4 *Vertical Channel Stability*

The stream channel longitudinal profile was examined over a length of 700 feet, extending from upstream of Culvert 125-1806W34G to the confluence with Vance Creek downstream of US 12 (see Figure 13). The elevation of the culvert outlet hanging over the channel bed is evident in the profile. Despite being elevated, the downstream water surface is likely often above the culvert invert. Water from Vance Creek backs up into the unnamed stream channel and through the culvert.

An avulsion, incision, or headcutting is not expected with a culvert replacement at this site. When there is water in the channel upstream of the US 12 crossing, it is conveyed downstream without creating any noticeable sediment deposits that would be eroded upon culvert replacement. The large quantity of reed canarygrass lining the upstream channel/ditch serves to slow the flow velocities as water approaches the culvert, further reducing the potential for incision.

The streambed elevation through the new culvert will match the channel bed elevation on either side of US 12. This change will allow for a greater volume of backwater to enter the culvert from the downstream side. As a result, more water may reach the agricultural ditch and remain ponded in the ditch on the upstream side of US 12 until the Vance Creek tailwater recedes. This situation should not cause problems for agricultural field drainage because of the high infiltration rates of the soils upstream of the culvert.

Aggradation of the unnamed stream channel is not expected as a result of replacing the US 12 culvert. The source of sediment from the upstream reaches is bank erosion where the channel flows through Elma. This source is over 3,000 feet upstream of US 12 and any sediment traveling downstream is deposited before reaching the culvert. The ponded backwater downstream of the highway carries very fine sediments and deposits them in the channel and adjacent wetland. There is a small potential for fine silts and clays to deposit within the new culvert via backwater when the unnamed stream is not flowing. These deposits would likely be transported downstream when there is flow from upstream.

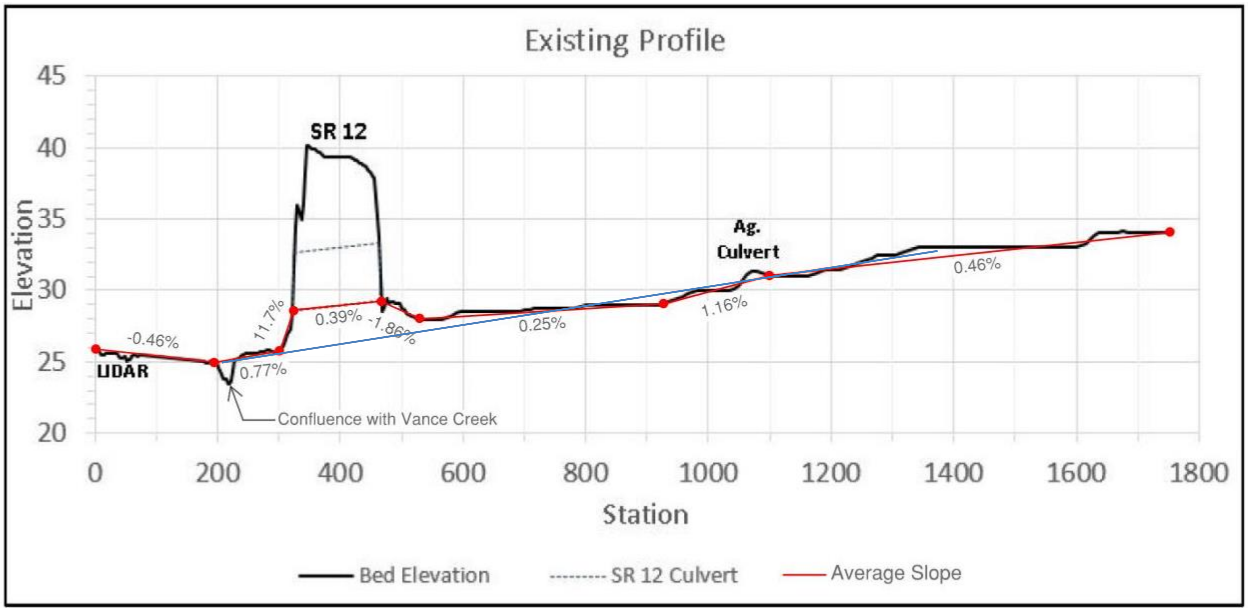


Figure 13: Longitudinal profile. Flow is from right to left.

2.7.5 Channel Migration

The stream channel upstream of Culvert 125-1806W34G is in a maintained ditch between agricultural fields and is armored farther upstream in the city of Elma. There is no likelihood of channel migration beyond the straight ditch. Any changes occurring in the City of Elma would be a result of human intervention and restoration projects in the future.

Downstream of US 12 the stream flows for a short distance of 100 feet from the culvert outlet to the confluence with Vance Creek. Backwater may travel up the unnamed tributary from Vance Creek, particularly when the nearby Chehalis River is in flood stage. The short length of the reach between the US 12 crossing and the confluence with Vance Creek, combined with the likely effect of backwater during a large flow event, indicates that the potential for channel migration in this downstream reach is negligible. There is no indication of any past channel migration visible on local area LiDAR. Available LiDAR for the drainage basin is from 2012 and 2017. Overall, the channel is at a low risk for channel migration.

Although the project site is within the Chehalis River floodplain, there are no defined floodplain flow paths. When the river is at flood stage there is slow-moving water surrounding the project area. The unnamed stream channel has been altered to flow within a ditched geometry and has not created additional flood flow pathways.

3 Hydrology and Peak Flow Estimates

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 247 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 55.1 percent, yielding a projected 2080 100-year flow of 383 cfs.

WSDOT 2022 guidelines (WSDOT 2022a) offer multiple methods by which the flows in a drainage basin may be calculated. Three of these methods rely on the USGS regression equations specific to the location. At the PHD level, the team from Herrera found that StreamStats (USGS 2016) was unable to correctly define the drainage basin due to the minimal gradient in the lower part of the basin. Instead they relied on the stream delineation from Grays Harbor County combined with field reconnaissance to define drainage basin boundaries and drainage area that accounted for stormwater runoff from Elma, agricultural drainage patterns, and area topography. They chose to be conservative in the inclusion of agricultural drainage. It is not certain that the fields far to the east of the unnamed tributary drain to Culvert 125-1806W34G, but they are conservatively included in the drainage basin area.

Herrera applied the Flood Q regression tool to determine flow rates at a range of mean recurrence intervals (Table 4). The specific rainfall region was determined from the map of regression regions in Washington State. The mean annual precipitation value used in the computations for the 30-year annual precipitation data for years 1981 through 2010 as resampled on a 30-meter cell size is 67.94 inches over a drainage area of 1.94 square miles (PRISM 2021). All of Grays Harbor County, including the project location, is in the USGS regression Region 4.

Table 4: Peak Flows for the Unnamed Tributary to Vance Creek at US 12

Mean recurrence interval (MRI) (years)	USGS regression equation (Region 4) (cfs)
2	69
10	110
25	141
50	213
100	247
500	326
Projected 2080 100	383

4 Water Crossing Design

This section describes the water crossing design developed for US 12 MP 19.17 unnamed tributary to Vance Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for the unnamed tributary to Vance Creek at US 12 MP 19.17.

The channel cross section was designed to mimic the geomorphology of the upstream and downstream reaches since a reference reach was not identified. The proposed channel is realigned to soften the 90 degree bend at the confluence with Vance Creek. The channel cross section shape is consistent throughout the crossing and near US 12 but varies near the confluence with Vance Creek.

4.1.1 Channel Planform and Shape

The WCDG requires that the channel planform and shape mimic conditions within a reference reach. However, there is no available reference reach for this channel. Upstream and downstream of US 12 the unnamed stream channel has been highly manipulated by residents in the area. The proposed channel geometry, shown in Figure 14, is based on channel measurements as described in Section 2.7.2. The channel design replicates the general channel shape in the vicinity of the crossing and includes 6.5-foot floodplain benches on either side of the channel. Upstream and downstream of the bridge crossing, the base width of the designed channel and floodplain benches match the 25-foot hydraulic opening. The morphology of this design consists of low gradient cross slopes of 10H:1V across the channel bottom, 2H:1V side slopes to form channel banks, and 10H:1V floodplain benches that serve to accommodate wildlife passage.

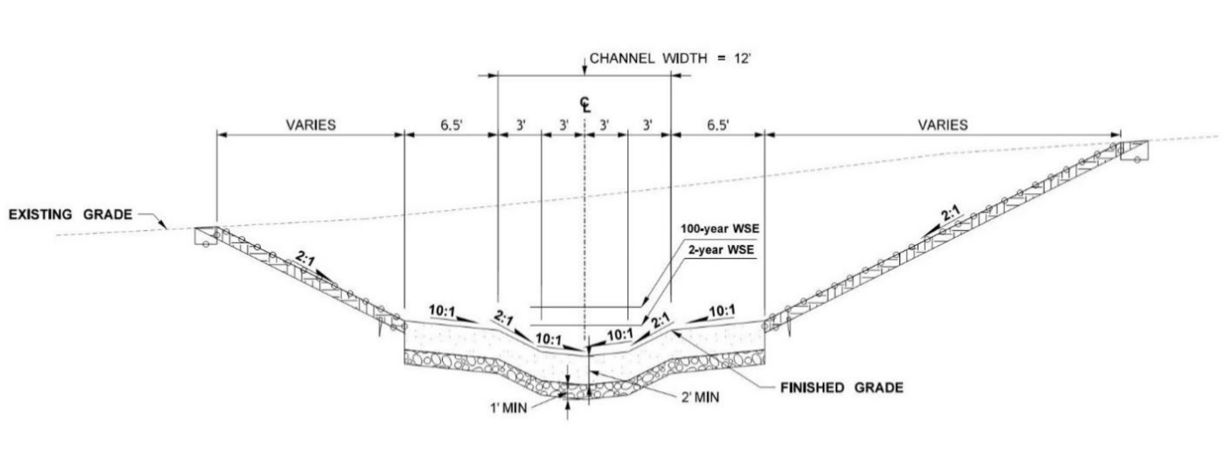


Figure 14: Design cross section

The proposed channel beneath the structure was compared to cross sections measured upstream and downstream of the reconstructed reach as shown in Figure 15. This shows that there is continuity through the crossing and the channel is expected to perform similarly to the adjacent reaches.

The proposed channel depth at bankfull conditions is 1.8 feet, while the modeled 2-year depth in proposed conditions during low flow Chehalis River circumstances is approximately 2.0 feet through the crossing. During construction, a low-flow channel will be field-fit that connects habitat features together so that the project does not form a low-flow barrier. The low-flow channel will be as directed by the engineer in the field.

During large flood events in the Chehalis River, flows through the proposed 25-foot hydraulic opening are expected to adjust the shape of the designed channel. The channel complexity that forms will aid in maintaining a stable channel planform and channel morphology over time. See Section 4.3.2 for more detailed discussion of the channel complexity design.

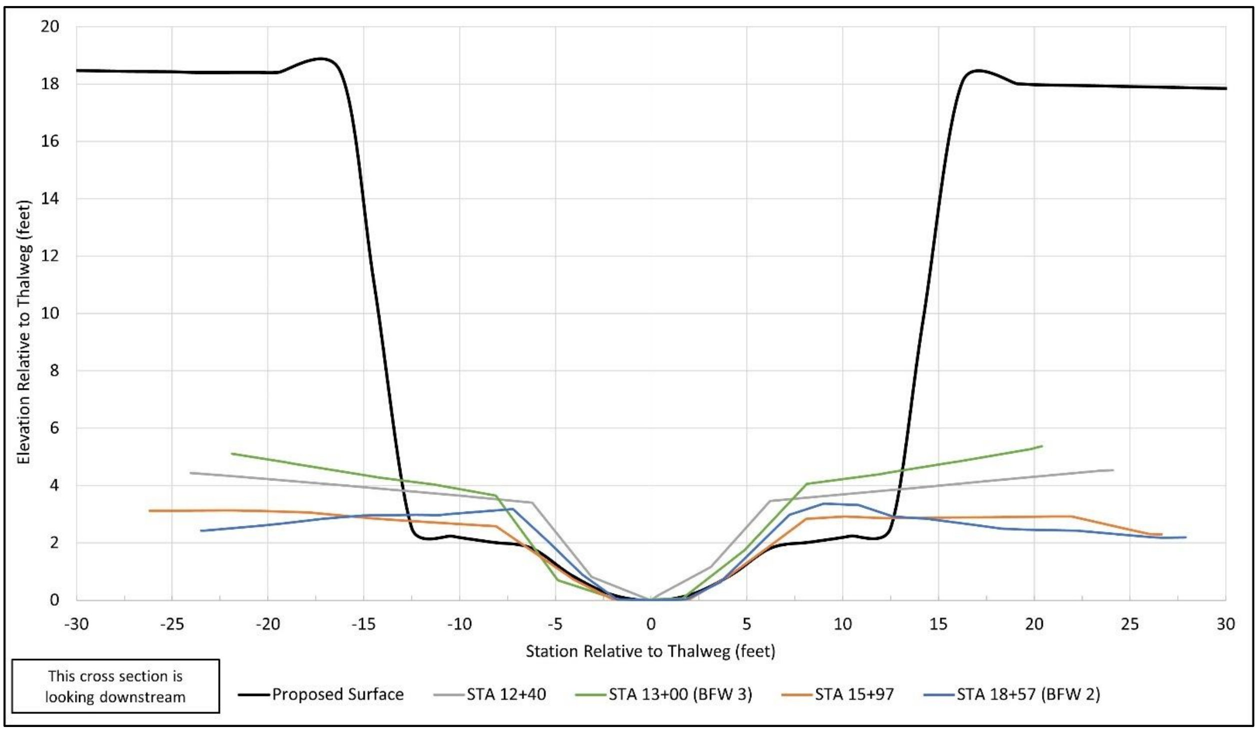


Figure 15: Proposed cross section superimposed with existing survey cross sections

4.1.2 Channel Alignment

The proposed channel alignment crosses US 12 at a 5-degree skew, which differs from the 18-degree skewed existing culvert. This change allows for a smoother confluence with Vance Creek, as opposed to the existing confluence where the unnamed tributary enters Vance Creek at an almost 90-degree angle. The new alignment introduces mild curves upstream and downstream of the bridge, however, the introduction of true sinuosity is limited by the proximity of the confluence, which is almost immediately downstream of the crossing. See Appendix D for design plans.

4.1.3 Channel Gradient

The existing channel gradient is influenced by the perched culvert, causing differing channel gradients upstream and downstream of the structure. The average gradient in the project area is 0.7 percent. The vertical alignment will be adjusted and lowered to tie in at the elevation of the channel bottom upstream and downstream of the crossing, including at the confluence with Vance Creek (see Figure 16). The proposed channel gradient through the bridge crossing is 0.63 percent, which is similar to the natural gradient of the channel resulting in a slope ratio of 0.9.

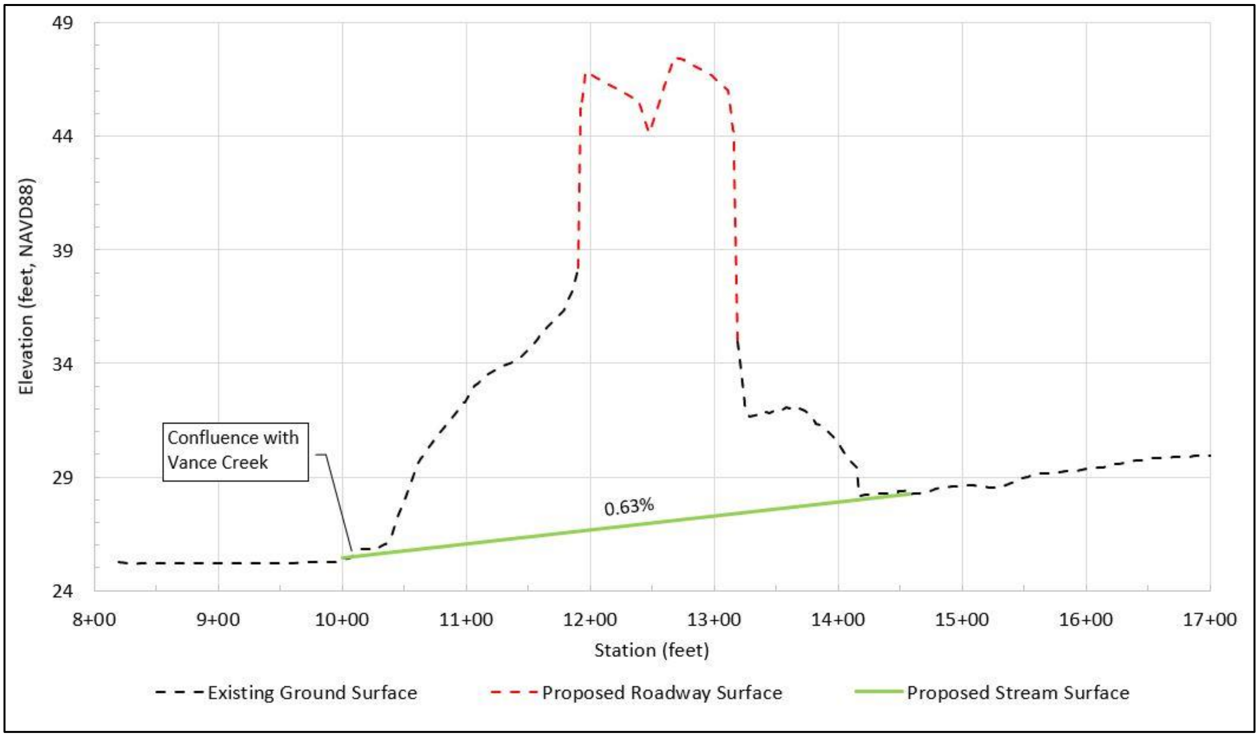


Figure 16: Proposed stream profile

The upstream gradient varies between 0.5 and 1.0 percent due to channel manipulation. When compared to the design slope, the slope ratio remains around 1. This is true through the first few hundred feet upstream of the US 12 crossing. Beyond this point the gradient decreases to approximately 0.5 percent.

As is discussed in Section 7, no long-term aggradation or degradation is expected at this crossing.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 17 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

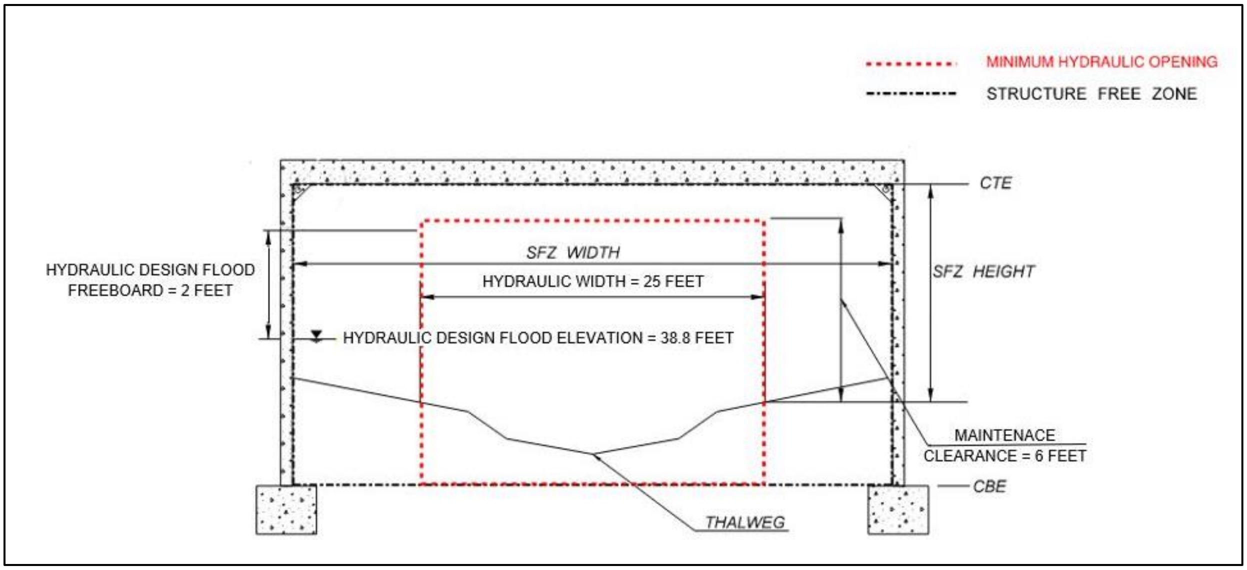


Figure 17: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the unconfined bridge criteria design method was determined to be the most appropriate at this crossing because according to the WCDG, an unconfined bridge should be considered for a site if the Floodplain Utilization Ratio (FUR) is greater than 3.0, the stream has a bankfull width of greater than 15 feet, the channel is believed to be unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, or the culvert would be very long.

Even though the unnamed tributary is small with a bankfull width of less than 12 feet (Section 2.7.2), the FUR is greater than 3.0 for the 100-year flood event (Section 2.7.2.1), resulting in constricted flow and velocity accelerations through the crossing that are exaggerated by the significant interaction of the Chehalis River backwater discussed in Section 5 of this report. Because the FUR is greater than 3.0, the unconfined bridge design width criteria are the appropriate design criteria for this project.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 17 feet was determined to be the minimum starting point.

The bankfull width was determined to be 12 feet (see Section 2.7.2). The minimum width for the crossing, calculated using Equation 3.2 in the WDFW 2013 Water Crossings Design Guidelines, would be 16.4 feet. For an unconfined system, the width of the structure is determined by an evaluation of the velocity ratio, which is defined as the flow velocity in the channel through the structure divided by the flow velocity in the channel immediately upstream of the structure if the roadway fill were removed entirely. The design criteria require the velocity ratio to be close to 1.0 in the simulated 100-year flood event. The WSDOT Hydraulics Manual (HM) states that if an existing structure is being replaced by a new structure, a velocity ratio of up to 1.1 is acceptable.

Velocity ratios were evaluated during PHD using a range of bridge span widths. A significant factor in this evaluation was the inclusion of the 100-year flood in the Chehalis River. Flood waters from the Chehalis River extend to US 12 and beyond during high flow events. The effect of the Chehalis River flood waters is significant because water flows from the south side of US 12 to the north side through cross culverts such as Culvert 125-1806W34G. When this happens, flow through the culvert runs in reverse pushing Chehalis River floodwater upstream along the unnamed tributary to Vance Creek. This flow is severely contracts through the culvert opening both on the rising limb as flooding is increasing and on the falling limb as floodwaters are receding.

To evaluate the hydraulic opening width, multiple hydraulic widths were evaluated at a condition where 1) there is a 100-year flood event on the unnamed tributary and a 2-year flood event on the Chehalis River, and 2) there is a 100-year flood event on the unnamed tributary and low flow in the Chehalis River. Table 5 and Table 6 show modeled flow velocities for these scenarios from a location approximately 30 to 40 feet upstream of the US 12 crossing and from the location within the US 12 crossing were the peak velocity occurred. The velocity ratios meet the HM criteria for a 25-foot span bridge for the steady state analysis.

Table 5: Velocities of Various Hydraulic Openings During 100-Year Flow in Unnamed Tributary to Vance Creek with 2-Year Chehalis River Backwater Effect

Structure Opening Width (ft)	Velocity Upstream of Structure (ft/s)	Velocity Through Structure (ft/s)	Velocity Downstream of Structure (ft/s)	Ratio of Velocity Through Structure to Upstream
17	2.6	3.0	2.4	1.2
20	2.6	4.0	2.4	1.5
25	2.6	2.6	1.9	1.0
30	2.2	1.7	1.8	0.8
60	2.4	1.4	1.7	6.0

Table 6: Velocities of Various Hydraulic Openings During 100-Year Flow in Unnamed Tributary to Vance Creek without Chehalis River Backwater Effect

Structure Opening Width (ft)	Velocity Upstream of Structure (ft/s)	Velocity Through Structure (ft/s)	Velocity Downstream of Structure (ft/s)	Ratio of Velocity Through Structure to Upstream
17	4.6	5.8	7.0	1.3
20	4.4	6.0	6.4	1.4
25	5.8	6.1	6.0	1.1
30	4.4	4.1	6.0	0.9
60	4.0	2.6	6.0	0.7

When a larger than 2-year flood of the Chehalis River is modeled, the backwater flow in the unnamed tributary to Vance Creek is so severe that the velocity ratio through the structure is always larger than 1.0, no matter how large the hydraulic opening. So, this scenario was not included in the design decisions. Based on the factors described above, a minimum hydraulic width of 25 feet was determined to be necessary to allow for natural processes to occur under normal flow conditions.

The projected 2080 100-year flow event in the tributary channel was evaluated. Table 7 compares the velocities of the 100-year and projected 2080 100-year events during periods of low Chehalis River levels (no backwater effect). No size increase was determined to be necessary to accommodate climate change. A minimum hydraulic opening of 25 feet is recommended. Lateral migration is expected to be limited at this site as the existing conditions show very little lateral instability primarily due to the straightening of the channel and the upkeep of the channel as an agricultural ditch.

Table 7: Main channel velocity comparison for 25-foot structure

Location	Velocity for 100-Year Tributary + Low Chehalis River (ft/s)	Velocity for Projected 2080 100-Year Tributary + Low Chehalis River (ft/s)
Upstream of structure (STA 13+63)	3.1	2.9
Through structure (STA 12+50)	4.2	5.1
Downstream of structure (STA 11+77)	3.5	4.2

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on bankfull width, is 3 feet above the 100-year water surface elevation (WSE) (Barnard et al. 2013, WSDOT 2022a).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE of the unnamed tributary to Vance Creek. The backwater during a Chehalis River flood event dominates all flow scenarios in the unnamed tributary. The WSE of the 2080 projected 100-year flow rate for the Chehalis River was not available to evaluate, therefore only the 100-year water surface elevation of the Chehalis River was considered for freeboard.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size within the crossing and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. The vertical clearance recommended by the wildlife memorandum is satisfied in the design, as discussed in Section 2.5.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	11+92	13+17
Thalweg elevation (ft)	26.6	27.4
Highest streambed ground elevation within hydraulic width (ft)	34.9	35.7
100-year WSE (ft)	38.8	38.8
2080 100-year WSE (ft)	NA	NA
Required freeboard (ft)	3	3
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	41.8	41.8
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	40.9	41.7
Required minimum low chord (ft)	41.8	41.8
Recommended minimum low chord (ft)	**40.9**	**41.7**
Design Low Chord (ft)	**41.8**	**41.8**

4.2.3.1 Past Maintenance Records

Olympic Region maintenance records for this site were unavailable at the time of writing.

4.2.3.2 Wood and Sediment Supply

There is no upstream supply of large woody debris, and the wood transport capacity of the unnamed tributary to Vance Creek is very low. However, there is a chance that large woody debris in transport in the Chehalis River could be transported to the downstream culvert/bridge outlet. Woody material moved by the Chehalis River can be very large, increasing the risk associated with woody material at the downstream end of the new structure. This risk is low at the existing culvert it is fully submerged during a 2-year Chehalis River flood and the culvert pipes are relatively small. Therefore, increasing the structure opening width to 25 feet increases the risk of LWM from the Chehalis River being deposited in or around the structure. However, the 3-foot vertical clearance will allow LWM to flow through the structure and will reduce the risk of a jam within the structure.

Channel bed aggradation due to sediment deposition is not anticipated to be a notable hazard at the site.

4.2.3.3 Impacts

Freeboard requirements with respect to the 100-year WSE of the Chehalis River are met by the proposed design. The low chord of the secant pile bridge is 41.8 feet, which meets both the required and recommended elevations. The design meets the recommended low chord elevation exactly because US 12 is being raised several feet to accommodate the vertical clearance.

4.2.3.4 Impacts to Fish Life and Habitat

Based on currently available information, the proposed freeboard of 3 feet will result in no substantial impacts to fish life and habitat.

4.2.4 Hydraulic Length

The hydraulic length of the structure design is 128 feet.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve US 12 through this corridor.

4.2.6 Structure Type

A secant pile bridge was selected to accommodate the 15 feet of scour that could occur through the hydraulic opening. Secant piles reduce the need for deep excavation to establish the bridge foundation. This structure type also simplifies a construction approach that allows the existing culvert to stay in place while the new bridge is built. The structure will include secant pile wing walls that sit parallel to US 12.

4.3 Streambed Design

This section describes the streambed design developed for the unnamed tributary of Vance Creek at US 12 MP 19.17.

4.3.1 Bed Material

The existing channel bed is covered in reed canarygrass. The sediment below the mat of grass is entirely fine-grained with significant organic matter content. No pebble count data was collected for this crossing because the streambed is comprised only of fine material.

Periodic flood events along the Chehalis River pose a risk of significant scour through the crossing, as described in detail in Chapter 7. Scour depths up to 15 feet are possible within the structure. Because of this scour risk, the channel bed design will have up-sized streambed material that is buried below 2 feet of native streambed material. The buried coarse material will be a sediment mixture of 60 percent 4-inch cobbles (WSDOT standard specification 9-03.11(2)) and 40 percent streambed sediment (WSDOT standard specification 9-03.11(1)). This material will be 4 feet thick. A layer of slash will be placed above and below each 1-foot lift of streambed mixture placed. Native streambed material will be retained and placed in a 2-foot thick layer above the streambed mixture containing slash material.

If exposed, the large sediment has the potential to benefit the fish present by improving water quality and oxygen levels compared to the current fine-grained sediment. Fish are unlikely to spawn in this reach, but resident fish and fish traveling up the unnamed tributary to escape high flows in the Chehalis will benefit from the improved streambed sediment.

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for the unnamed tributary to Vance Creek at US 12 MP 19.17.

4.3.2.1 Design Concept

LWM will be installed in open channel portions of the unnamed tributary to Vance Creek according to the Hydraulics Manual and Fox and Bolton (2007). All relevant calculations are included in Appendix F.

For a BFW of 12 feet, the minimum key piece of density is 3.35 key pieces per 100 feet. With 446 feet of regrading proposed at this site, the LWM targets are 15 key pieces, 52 total pieces, and a volume of 176.1 cubic yards.

To satisfy the large volume target, the proposed design incorporates buried logs. By burying some pieces, logs can be stacked vertically. This allows a larger volume of wood to fit within the regraded channel and still have most logs engaged within the channel's low flow area. The buried wood also provides anchoring for other pieces by lashing logs together. Buried logs will also inhibit scour along the channel during Chehalis River backwater events and buried logs take longer to decompose than surface logs so they will remain in the system longer.

The proposed design, shown in Figure 18 and Appendix D, incorporates 44 key pieces and 66 total pieces of LWM, which exceed the targets. As discussed in Section 8, slash is proposed within the buried structure. With the approval from the Quinault Indian Nation, the volume of the slash has been included in the total volume of proposed LWM calculation, resulting in a volume of 177.2 cubic yards, which exceeds the recommended volume. To ensure the constructability of the LWM design, three cluster types are proposed, as seen in Appendix D. The different clusters provide variability in habitat enhancement and aesthetics while providing clear plans for the contractor.

This site is not used for recreational swimming or boating. LWM will be low risk to recreational users on foot. All LWM is placed for habitat enhancement purposes. The placed LWM will provide cover and rearing habitat for Coho and trout, which may come to this reach after hatching. It will also provide cover for fish that come up the tributary during large Chehalis River floods to escape more turbid water. The channel design includes slight grades on the channel bed, creating a low flow channel at the center. Post construction, this low flow channel is expected to move in response to LWM and constructed meander bars. Fish stranding is not expected to be a risk during low flow conditions. Preformed pools are not recommended for this crossing.

The downstream segment of channel along the existing alignment will be retained as a backwater channel that will provide additional habitat for fish. It is anticipated that a variety of fish species will use this area as for refuge, especially during high flows in the Chehalis River.

The buried structure will be 128 feet long and 25 feet wide, so channel complexity within the crossing was considered in the design to prevent a flat, plane-bed, shallow flow condition from developing over time. Due to the small channel width, meander bars were included in the design to provide complexity within the culvert. Meander bars are strategically placed in the streambed within the crossing 40 feet apart on alternating sides. Three meander bars are placed inside the culvert. The meander bars are design with a top layer of coarsened bed material that is within the 2-foot top layer of native streambed material (see Section 4.3.1 for bed material design). Beneath this layer, one-man boulders will be added within the 4-foot coarse material layer. This will ensure that the meander bars remain engaged during a rare event of severe scour. Slash layers are proposed throughout the meander bars, further protecting them from scour events.

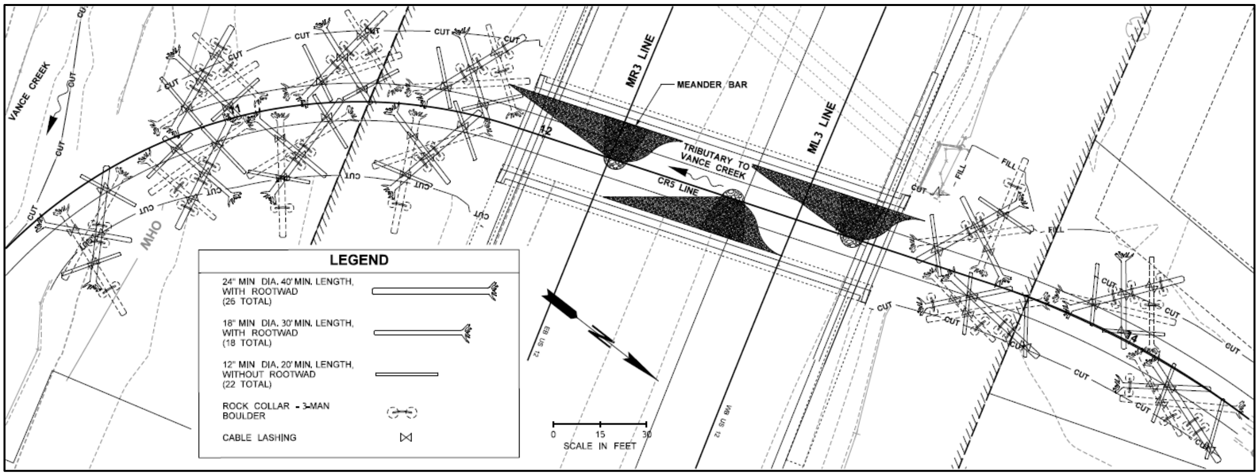


Figure 18: Conceptual layout of habitat complexity

4.3.2.2 Stability Analysis

For simple multi-log structures, large woody material stability analysis is typically completed using the USFS-supplied Computational Design Tool for Evaluating the Stability of Large Wood Structures Excel program. The interactions between logs are normally entered into the spreadsheet to determine the stability of each individual log in a structure. However, due to the complexity of the log interactions in the proposed clusters at this crossing, determining the individual stability of logs in a cluster was not feasible. Instead, the stability of the log cluster as a whole was determined. To do so, the USFS-supplied Excel program was used to determine the vertical and horizontal forces acting on each individual log, without accounting for interactions between logs. The forces occurring on individual logs were then summed to determine the total force occurring on the entire log cluster. This is a valid approach because, all logs in a cluster are lashed together, and therefore forces on a given log act on the whole cluster.

The stability calculations were conducted using the 2-year unnamed tributary to Vance with 100-year Chehalis River flood event. All calculations are included in Appendix F, and a summary of the stability of individual logs and entire clusters is shown in Table 9. The USFS-supplied tool's assumptions include:

- Flows are not highly turbulent
- Stable and uniform stream geometry
- No debris flows
- Relatively low energy stream that transports sediment smaller than cobbles
- Simple log geometry (e.g., no branches, no partial rootwads)

Both anchoring and lashing are required for all wood clusters to ensure stability due to the Chehalis backwater experienced at this crossing. The anchoring is provided by three-man boulder rock collars. Depending on the cluster type, either three or four rock collars are required per cluster. See Appendix D for the anchoring and lashing details.

Table 9: Summary of log ballast requirements

Cluster Type	Log (ID number)	Diameter (in)	Length (ft)	Vertical Force Balance (lbf)	Horizontal Force Balance (lbf)	Anchor requirements	
						Required ballast	Number of rock collars (three-man)
A	1	18	30	1,810	2	N/A	N/A
	2	24	40	67	3	YES	2
	3	24	40	-4,646	-26,577	YES	1
	4	24	40	-22,579	-82,755	N/A	N/A
	5	12	20	453	0	N/A	N/A
	6	12	20	453	1	N/A	N/A
	Cluster Total	-	-	-1,863	-26,571	-	-
B	1	18	30	1,813	2	N/A	N/A
	2	24	40	-2,049	-1,769	YES	3
	3	18	30	-1,960	-6,816	YES	1
	4	24	40	-15,003	-57,959	N/A	N/A
	5	12	20	453	0	N/A	N/A
	6	12	20	453	0	N/A	N/A
	Cluster Total	-	-	-1,289	-8,582	-	-
C	1	24	40	67	2	YES	2
	2	18	30	-302	-260	YES	1
	3	18	30	-1,960	-6,236	YES	1
	4	24	40	-12,938	-51,099	N/A	N/A
	5	12	20	453	1	N/A	N/A
	6	12	20	453	1	N/A	N/A
	Cluster Total	-	-	-1,288	-6,492	-	-

a. Assumes boulders with submerged specific gravity of 1.65.
b. Negative value indicates anchor and overburden moments exceed buoyant moments.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed US 12 unnamed tributary to Vance Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2.4 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for the unnamed tributary to Vance Creek with the SRH-2D models: (1) existing conditions with the existing twin 48-inch-diameter concrete culvert pipes and (2) proposed conditions with a 25-foot minimum hydraulic opening with the various flow regimes described below.

The hydraulic model was run using a subcritical flow regime assuming multiple combinations of upstream and downstream boundary conditions influenced by the Chehalis River and based on the likelihood of coincidental peak flows occurring in Vance Creek and the unnamed tributary (Kilgore 2010). The 2, 100, 2080 projected, and 500-year events in the Unnamed Tributary to Vance Creek were modeled during low flow Chehalis River conditions which lack a backwater effect on the crossing. To analyze the backwater conditions of the Chehalis River the 2-year event in the unnamed tributary was evaluated during a 2-year event in the Chehalis River as well as 100-year event in the Chehalis River.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT in February of 2020. Additional topographic survey was collected by David Evans and Associates, Inc in November of 2020. The survey data were supplemented with light detection and ranging (LiDAR) data (Grays Harbor county, 2012). Proposed channel geometry was developed from the proposed grading surface created by David Evans and Associates, Inc. All survey and LiDAR information is referenced against the NAVD 1988 vertical datum. The LiDAR data upstream and downstream of surveyed areas was modified to account for channel bathometry that is not included in LiDAR data. A presumed channel depth of 1 to 3 feet was "stamped" into the LiDAR data to provide a better representation of the channel in these areas for modeling.

5.1.2 Model Extent and Computational Mesh

The model extends from approximately 1,424 feet upstream of the existing US 12, MP 19.17 inlet to approximately 490 feet downstream of the existing outlet, covering a total channel length of 2,070 feet. Discontinuities near model edges are typically resolved within the nearest few cells. In this model there are over 330 cells in the computational mesh along the channel centerline from the inlet boundary condition to the crossing and over 40 cells from the proposed crossing to the outlet boundary condition. This number of cells buffers the site from edge effects ensuring reliable computations around the existing and proposed crossings.

The model meshes have an element density reflective of the complexity of the site conditions. The existing conditions model consists of 39,137 elements (see Figure 19 and Figure 20), while the proposed conditions model consists of 44,481 elements (see Figure 21 and Figure 22). Both existing and proposed conditions meshes utilize quadrilateral elements in the channel and triangular elements over the remaining surface area. The meshes have an approximate vertex spacing of 4.5 feet along the channel banks and an approximate 25-foot vertex spacing near the outer domain limits. Vertex spacing is 1.0 foot at the upstream boundary and 6.5 feet at the downstream boundary. The US 12 crossing in the proposed model has an average vertex spacing of 4.5 ft along the structure walls and 2.0 ft at the inlet and outlet.

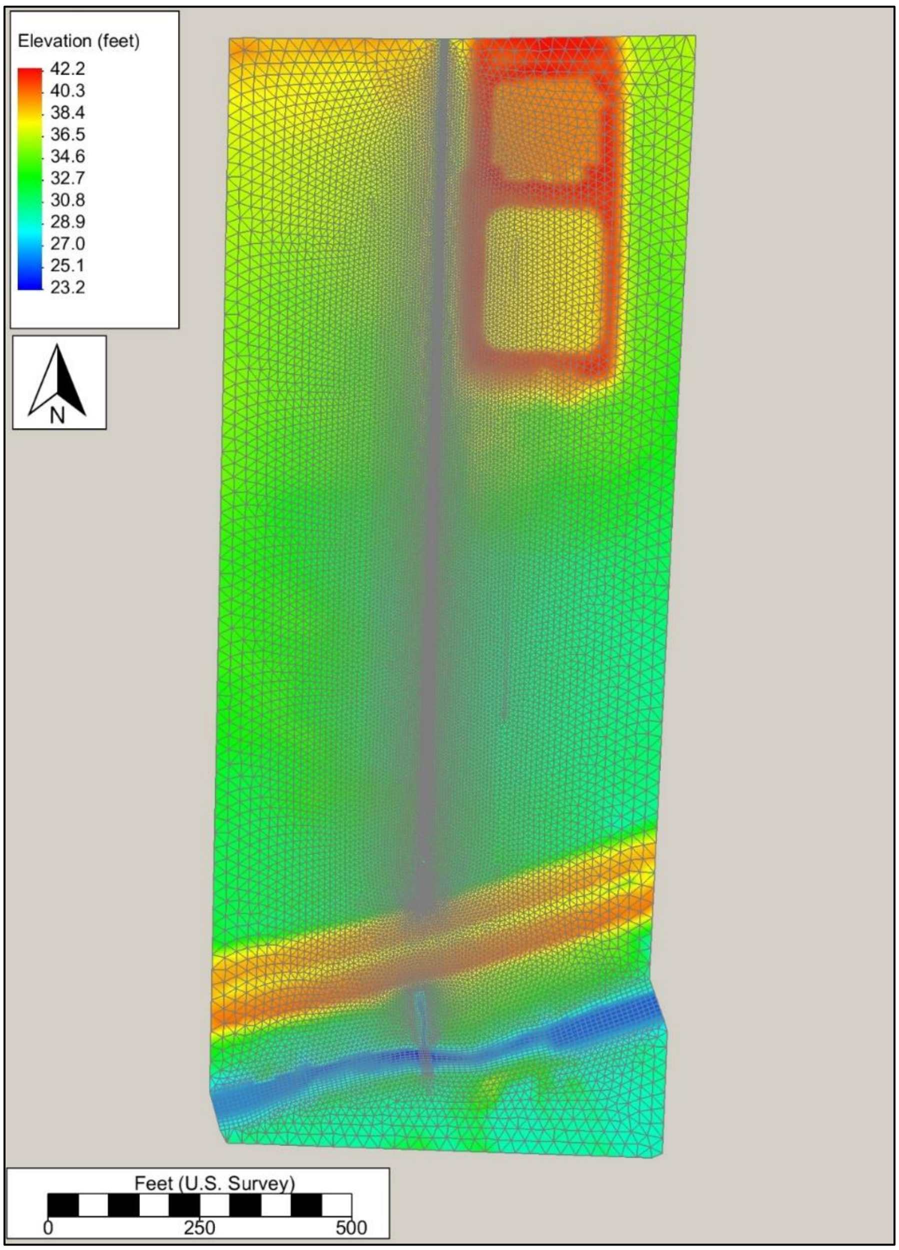


Figure 19: Existing-conditions computational mesh with underlying terrain

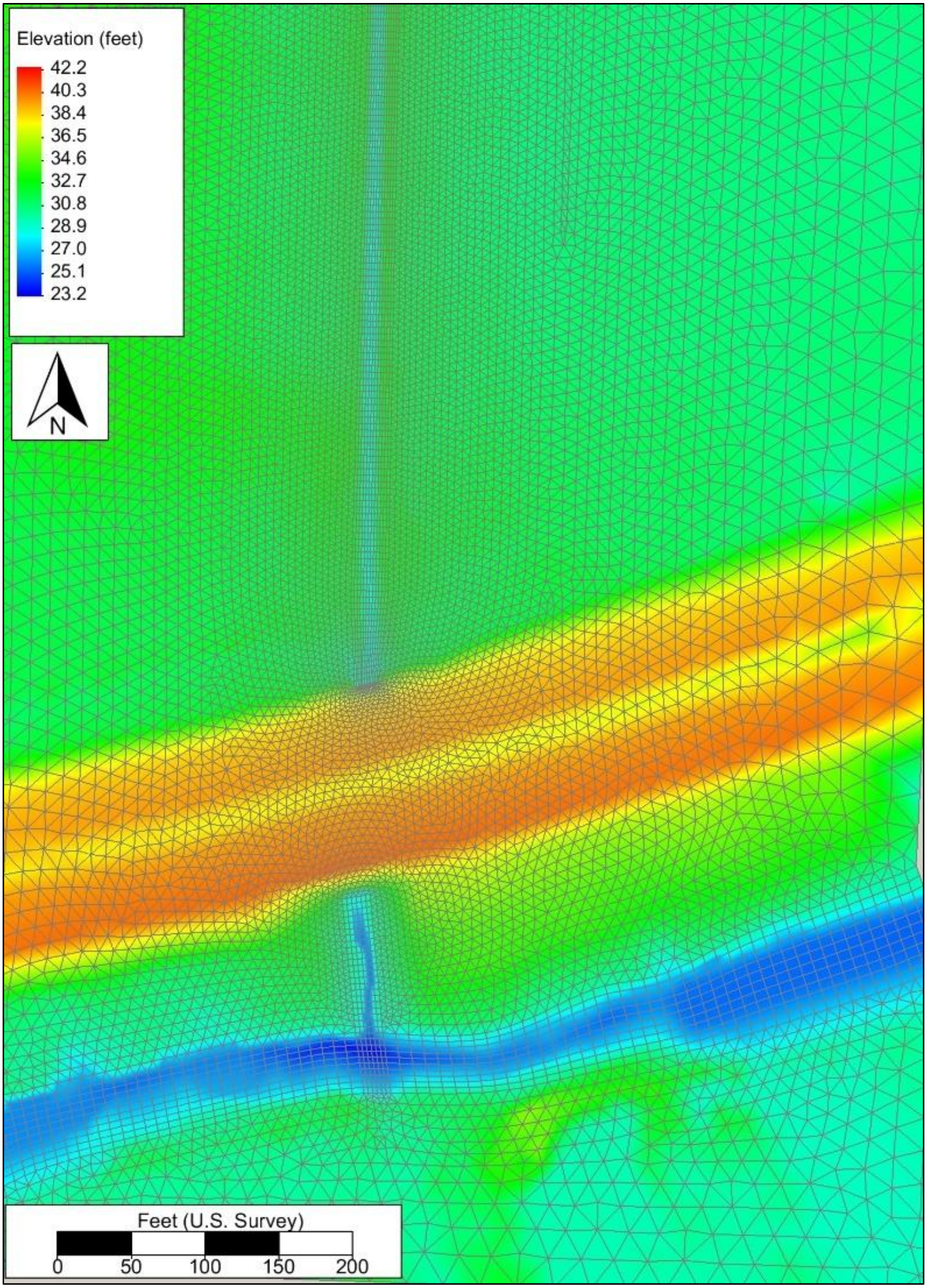


Figure 20: Existing-conditions computational mesh with underlying terrain zoomed to project area

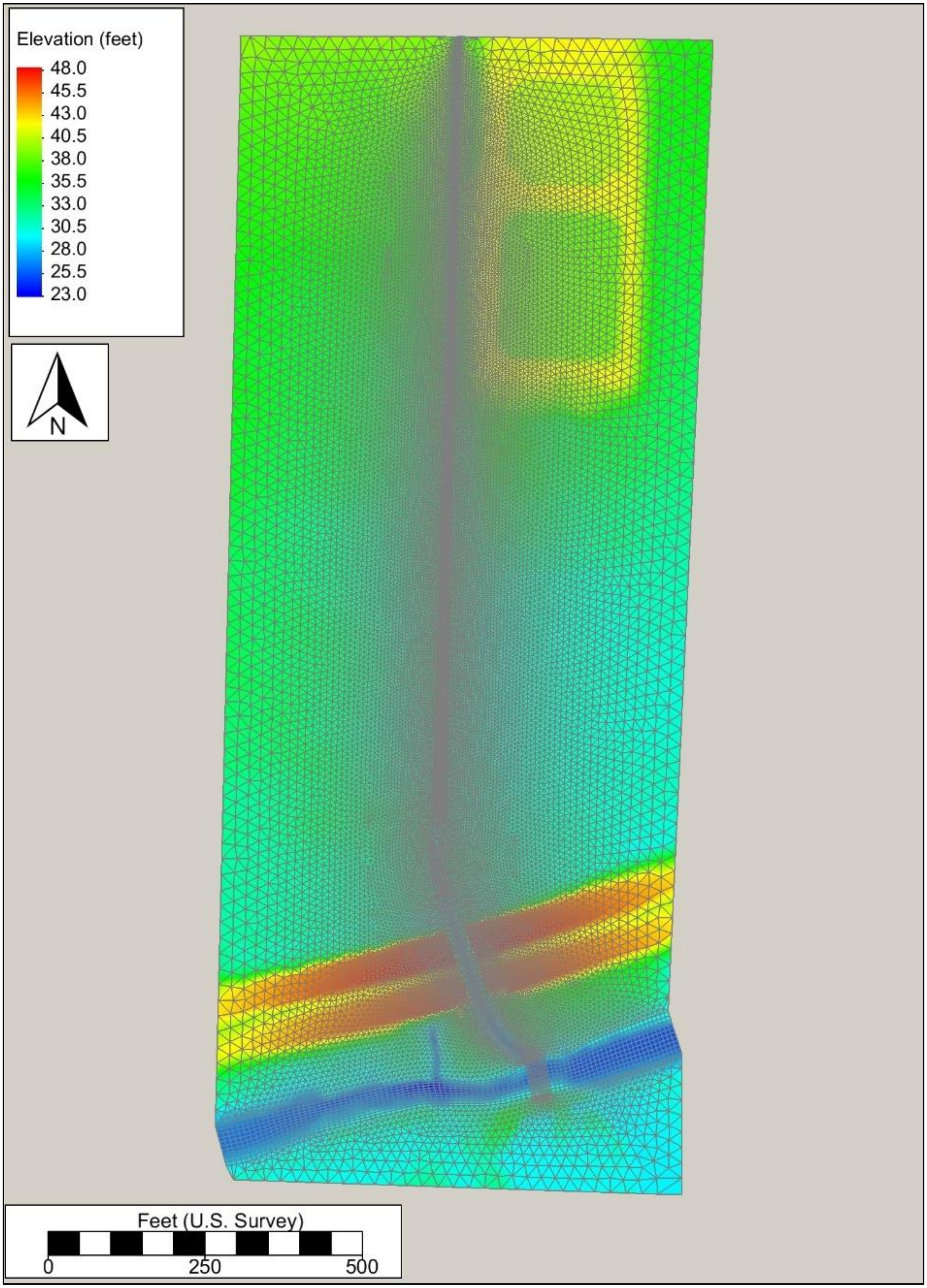


Figure 21: Proposed-conditions computational mesh with underlying terrain

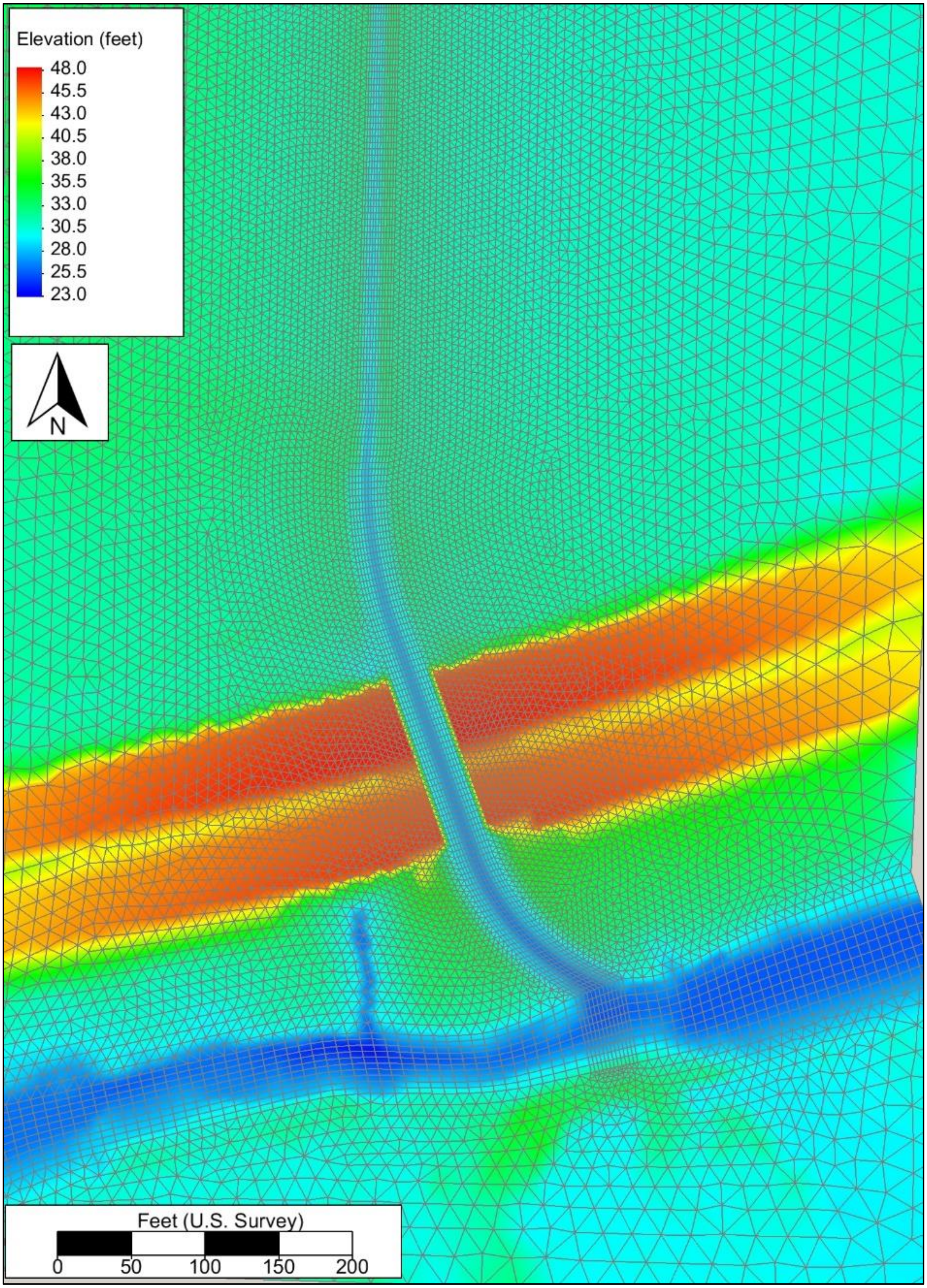


Figure 22: Proposed-conditions computational mesh with underlying terrain zoomed to project area

5.1.3 Materials/Roughness

Table 10 lists the roughness coefficients used in the hydraulic modeling taken from *Open Channel Hydraulics* (Chow, 1959) and evaluated by visual observation of site photographs. Existing and proposed conditions utilized the same roughness values. No-flow areas (i.e. buildings) and unassigned land cover types were not necessary to model the two conditions. Figure 23 and Figure 24 show the spatial distribution of the roughness conditions for the existing conditions model, while Figure 25 and Figure 26 show the distribution of the proposed model roughness conditions.

The main channel roughness values represent a straighten channel containing a fine sediment bottom lined with thick vegetation (reed canarygrass). The channel banks are representative of light brush and vegetation, while a slightly larger roughness value was used for wetland and brush areas of greater density. Large woody material (LWM) to the extent contained in the proposed conditions is not present in existing conditions. The roughness value for LWM in Table 10 represents channel spanning logs and root wads as discussed in Section 4.3.2.

Table 10: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Main Channel Upstream	0.035
Main Channel Downstream	0.04
Asphalt	0.016
Channel Banks	0.04
Agricultural Field	0.035
Wetland Area/Brush	0.05
Large Woody Material	0.08

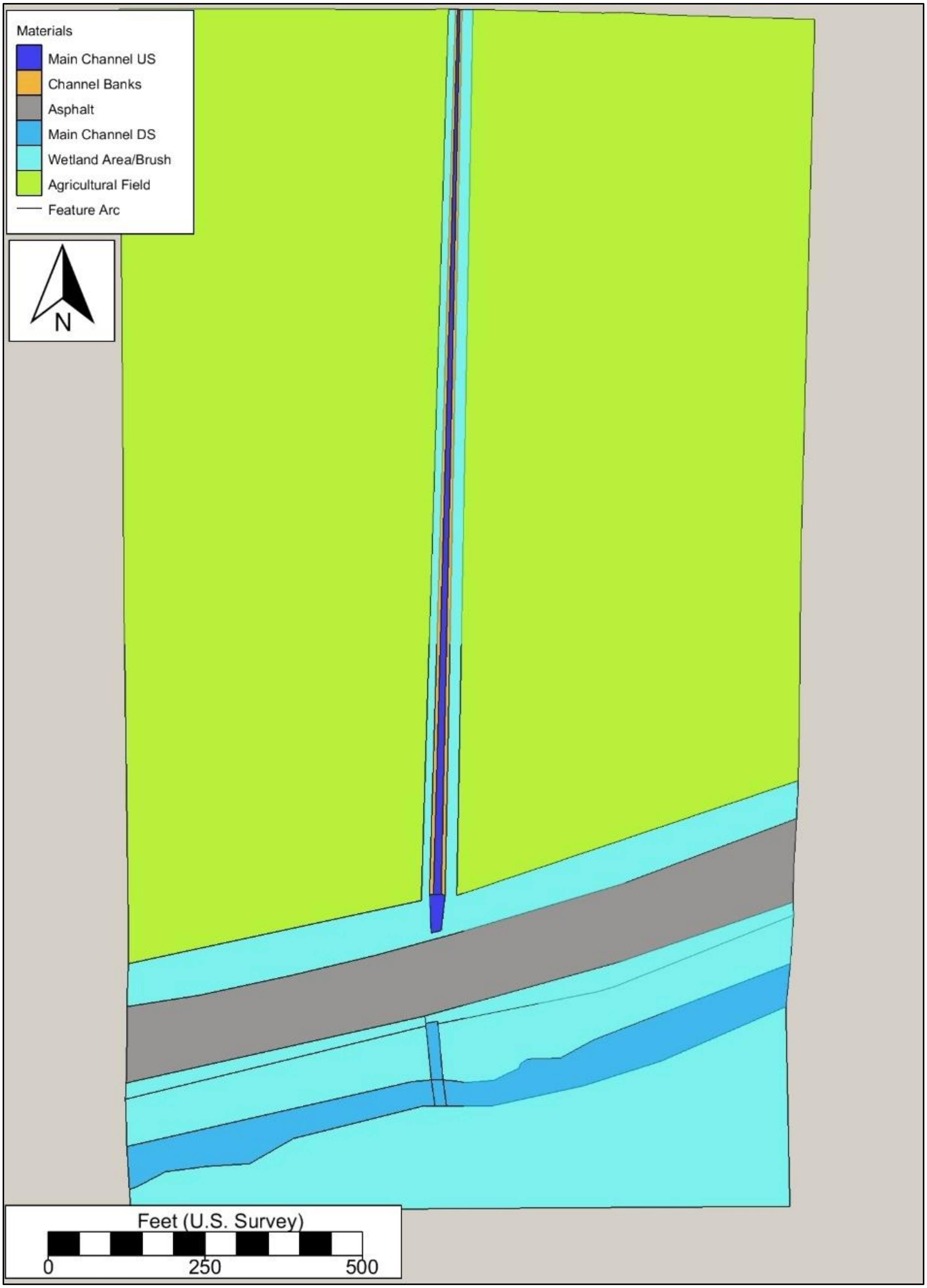


Figure 23: Spatial distribution of existing-conditions roughness values in SRH-2D model

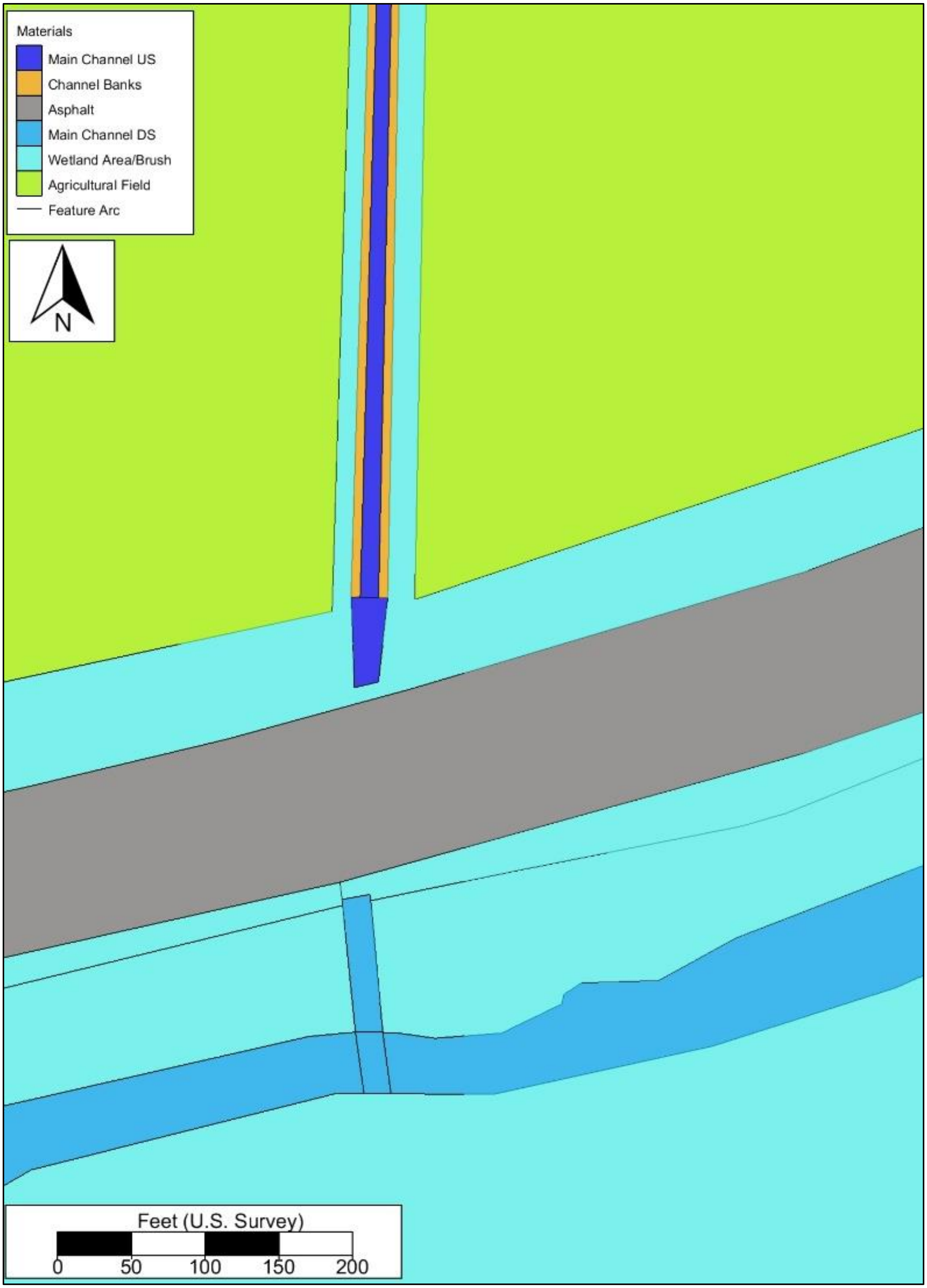


Figure 24: Spatial distribution of existing-conditions roughness values in SRH-2D model zoomed to project area

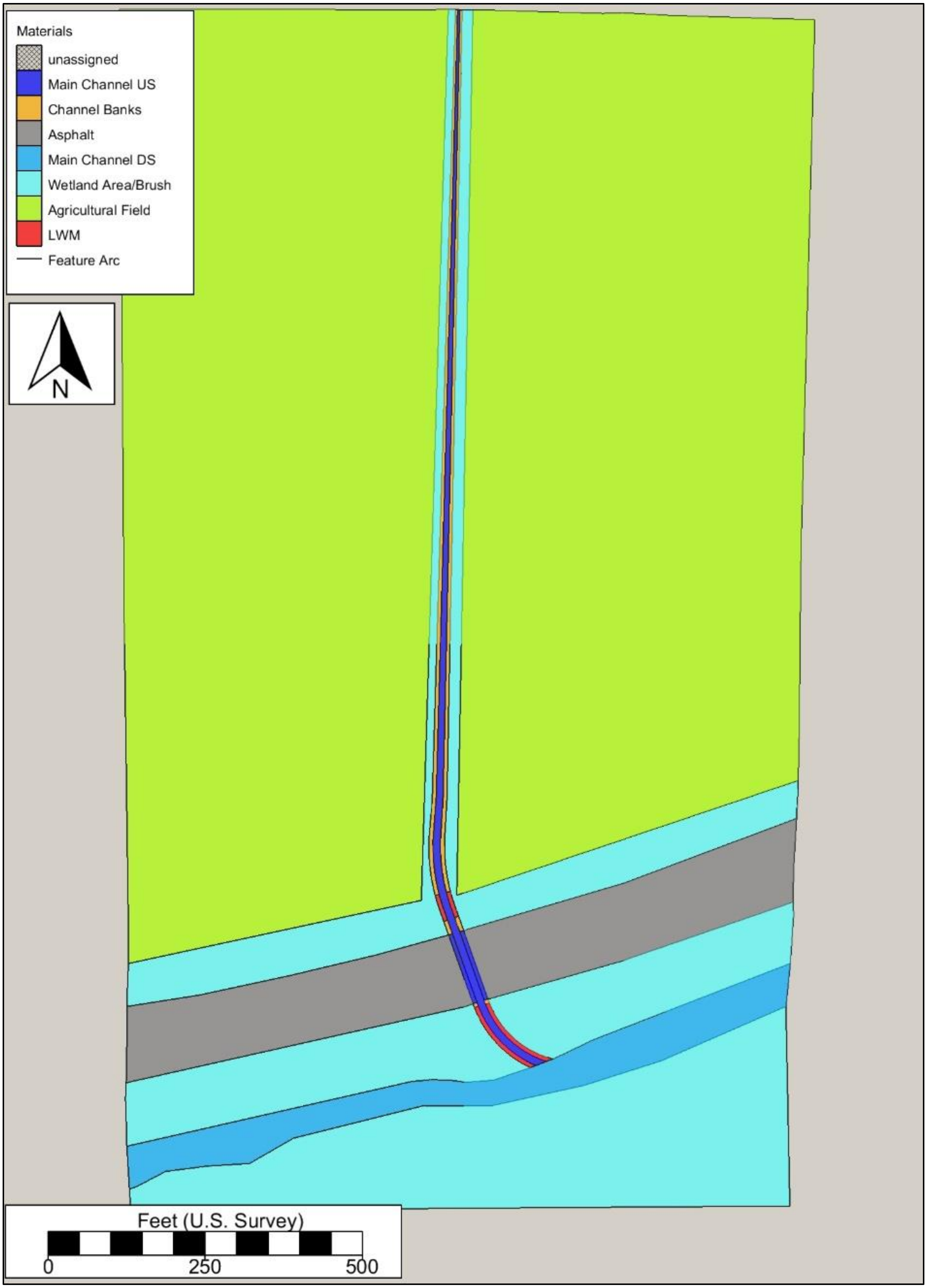


Figure 25: Spatial distribution of proposed-conditions roughness values in SRH-2D model

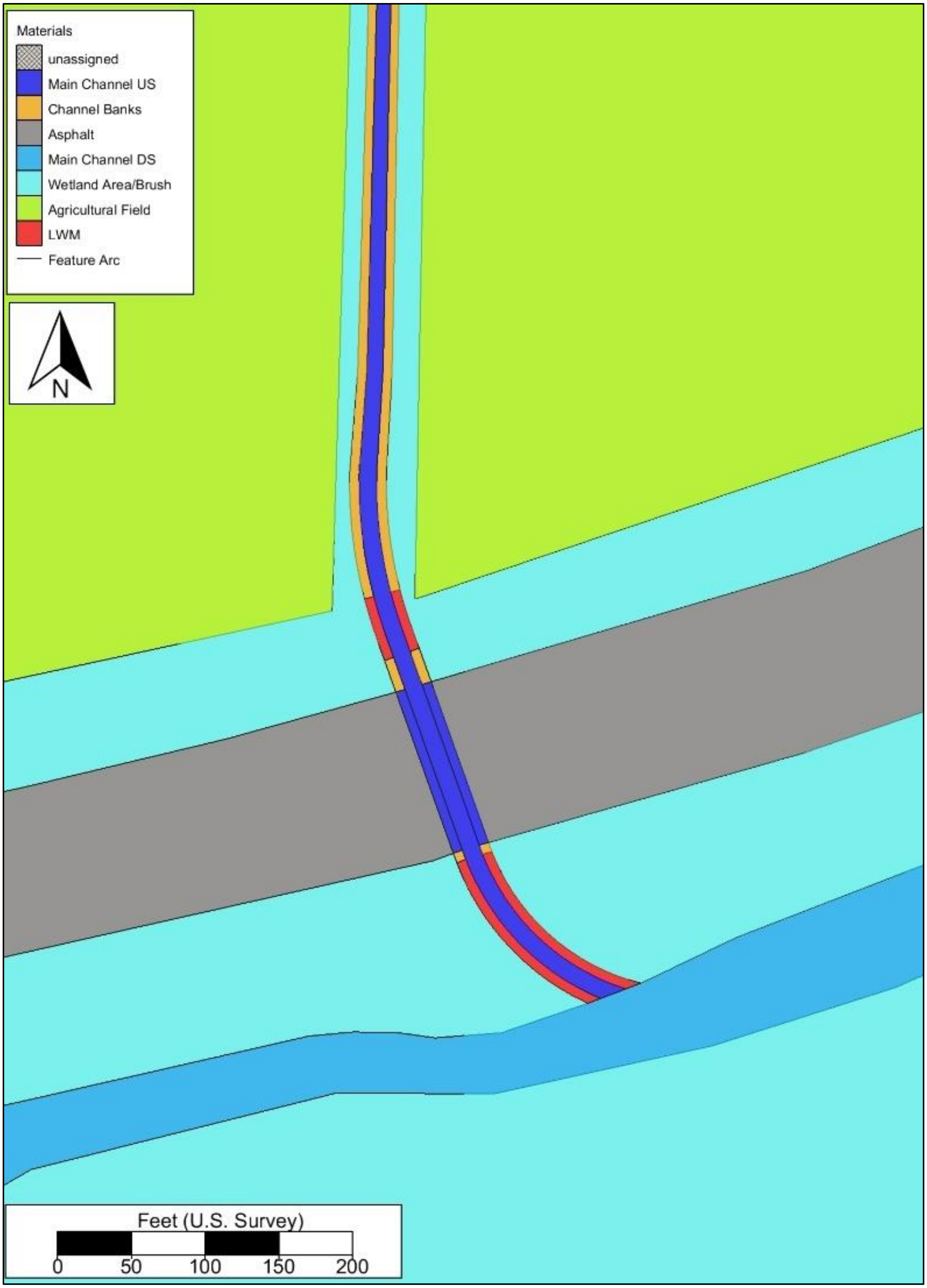


Figure 26: Spatial distribution of proposed-conditions roughness values in SRH-2D model zoomed to project area

5.1.4 Boundary Conditions

The existing conditions model contained four boundary conditions that are a subcritical inflow rate at the upstream limits, paired inlet and outlet boundaries at the existing culvert location, and a constant water surface elevation (WSE) at the downstream limits of the models. In the existing conditions model, a pair of boundary condition arcs were used to simulate the existing twin 4-foot diameter culverts crossing US 12 at the project site. The SRH-2D model simulates the culvert hydraulics by running the Federal Highway Administration's (FHWA) HY-8 culvert analysis software as an imbedded program within SMS and uses the boundary conditions as the interface between the programs. Culvert geometry, type, and other relevant site data required for the HY-8 computations were compiled from the WSDOT survey and DEA site visit. Figure 27 shows the HY-8 input data for the US 12 culvert in the existing conditions model. The proposed conditions model included two boundary conditions: a subcritical inflow rate at the upstream limits and a water surface elevation (WSE) at the downstream limits of the model. Figure 28 and Figure 29 show the location of these boundaries in the existing and proposed conditions models respectively.

The downstream boundary is governed by a low gradient backwater from both Vance Creek and the Chehalis River Floodplain. The first fixed water surface scenario assumed independence between the unnamed tributary and the Chehalis River. The constant water surface elevations of the low flow Chehalis River scenarios have calculated normal water surface elevations of 28.1, 30.5, 30.8, and 31.1 feet for the 2, 100, 500, and 2080 100-year events respectively. The calculated normal depths were based on StreamStats and USGS Regression Equation flow rates for Vance Creek using a channel slope of 0.0012 feet/feet with a composite Manning's Roughness of 0.045. Figure 30 contains a normal depth rating curve for the channel at the downstream boundary. The second fixed water surface scenario assumed a 2-year flow in the Chehalis River with a fixed water surface elevation of 31.8 feet, which would induce backwater through the existing culvert. While the final fixed water surface scenario assumed a 100-year flow in the Chehalis River with a fixed water surface elevation of 38.8 feet.

For both the existing and proposed conditions models, the upstream inflow boundary was specified using a time series table with peak flows equal to the recurrence interval being modeled (i.e. peak flows equal to the 2, 100, 500, and projected 2080 100-year). Each inflow boundary condition peak flow was achieved linearly in 5-minute time steps after 1 hour and held constant for 99 hours. The peak flowrates are provided in Table 4 The inflow and outflow boundary conditions were set far enough away from the US 12 MP 19.17 crossing so that these boundaries do not influence the hydraulic results at the project site. The model was run in steady-state mode for all simulated flows.

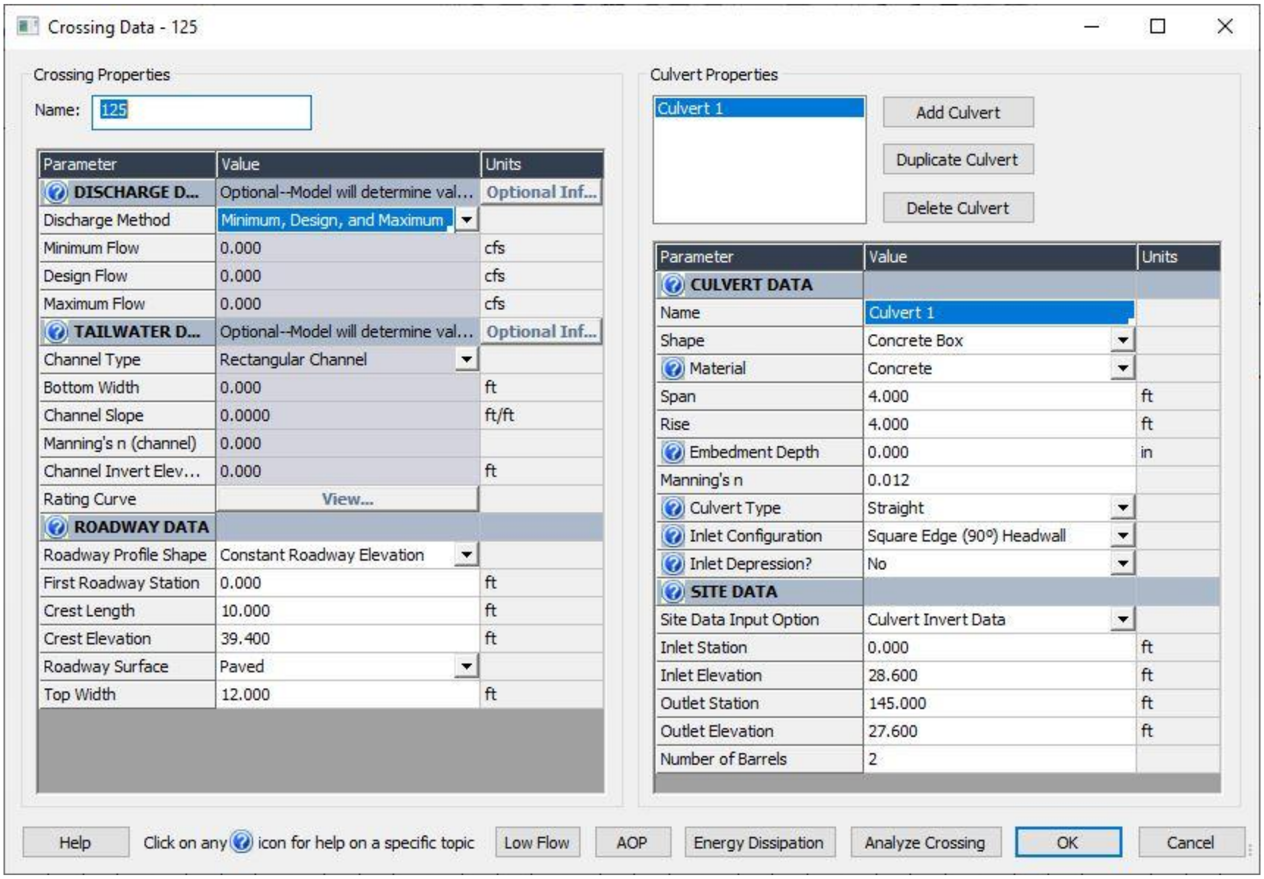


Figure 27: HY-8 culvert parameters

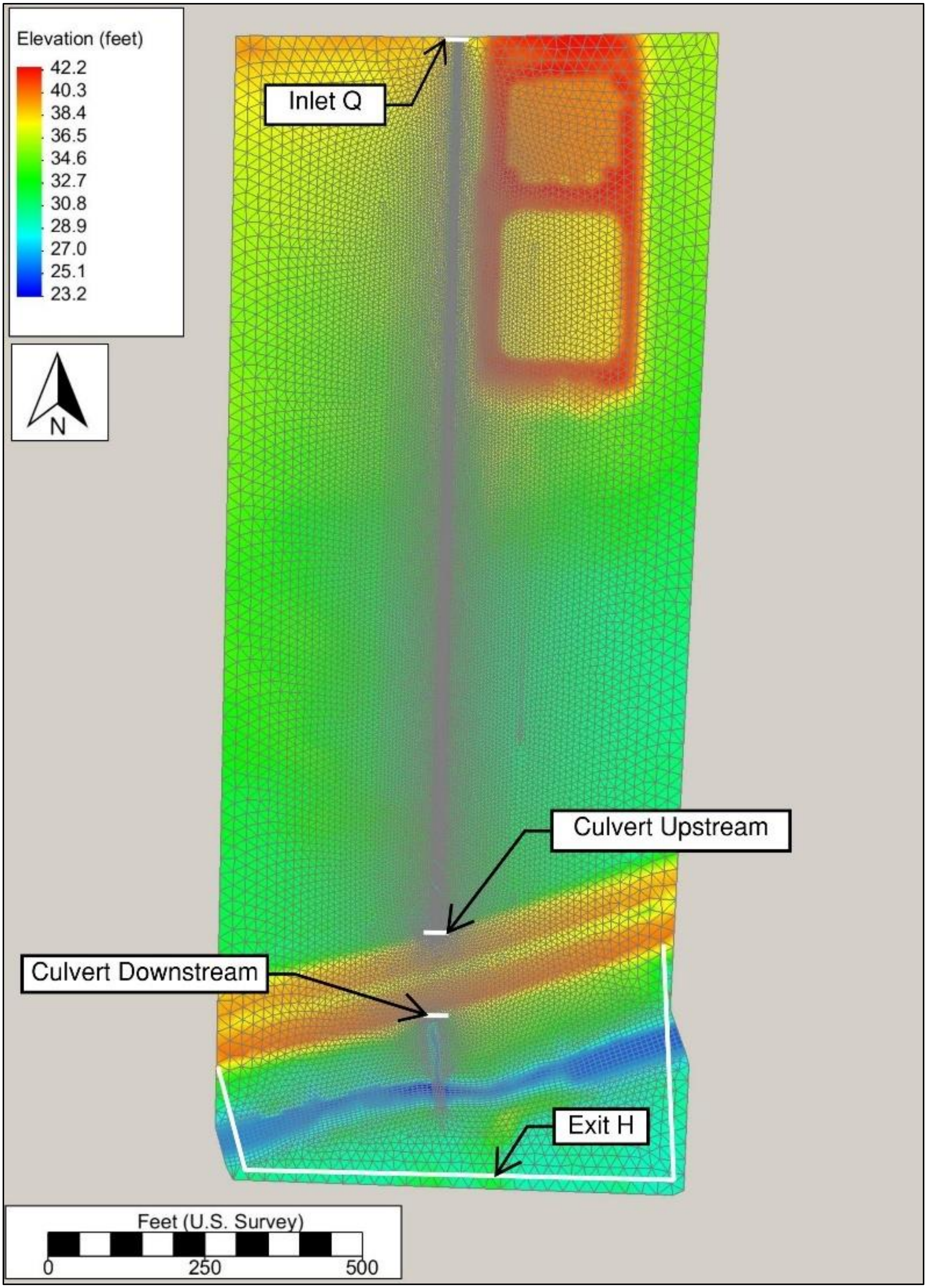


Figure 28: Existing-conditions boundary conditions

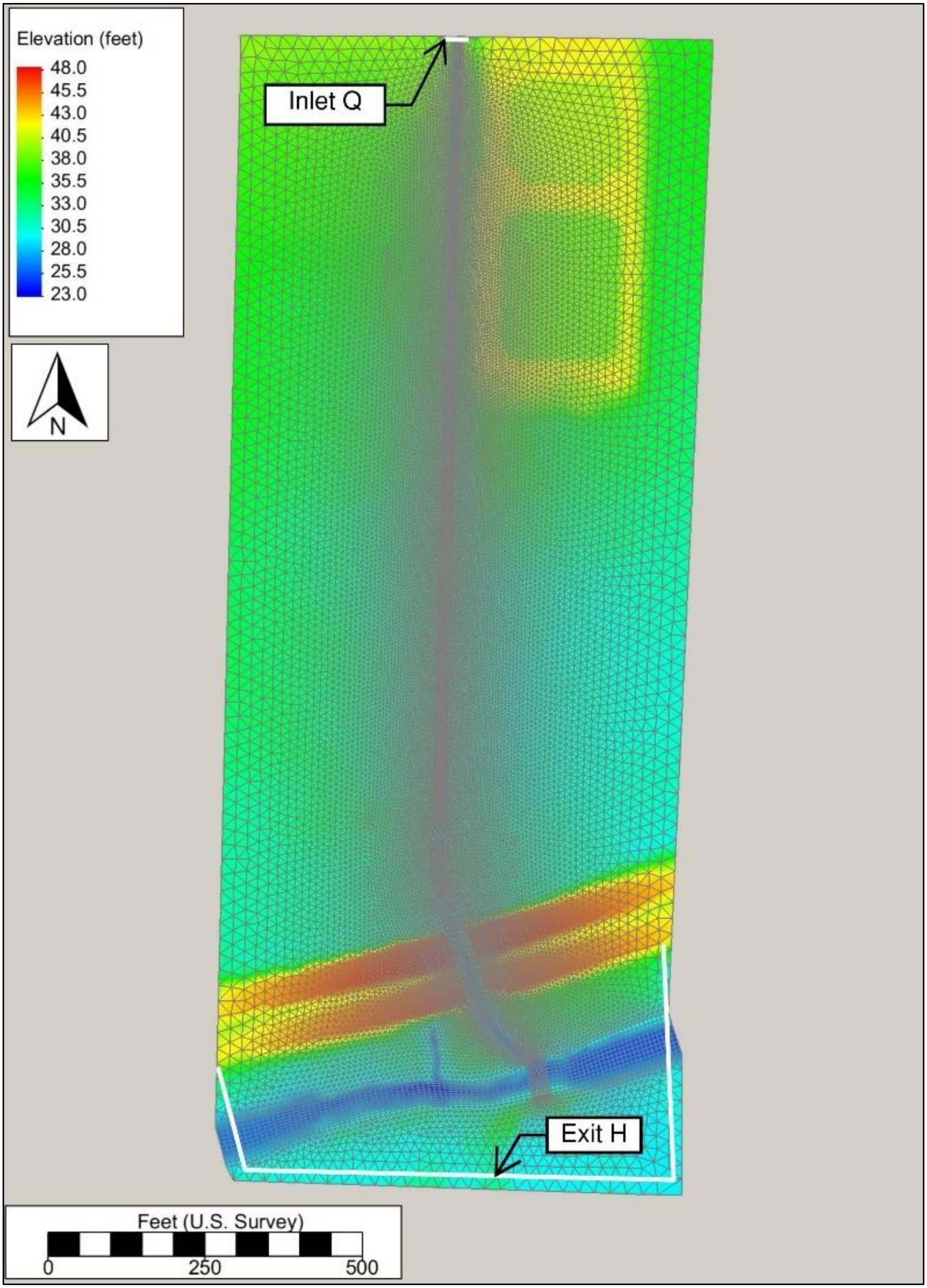


Figure 29: Proposed-conditions boundary conditions

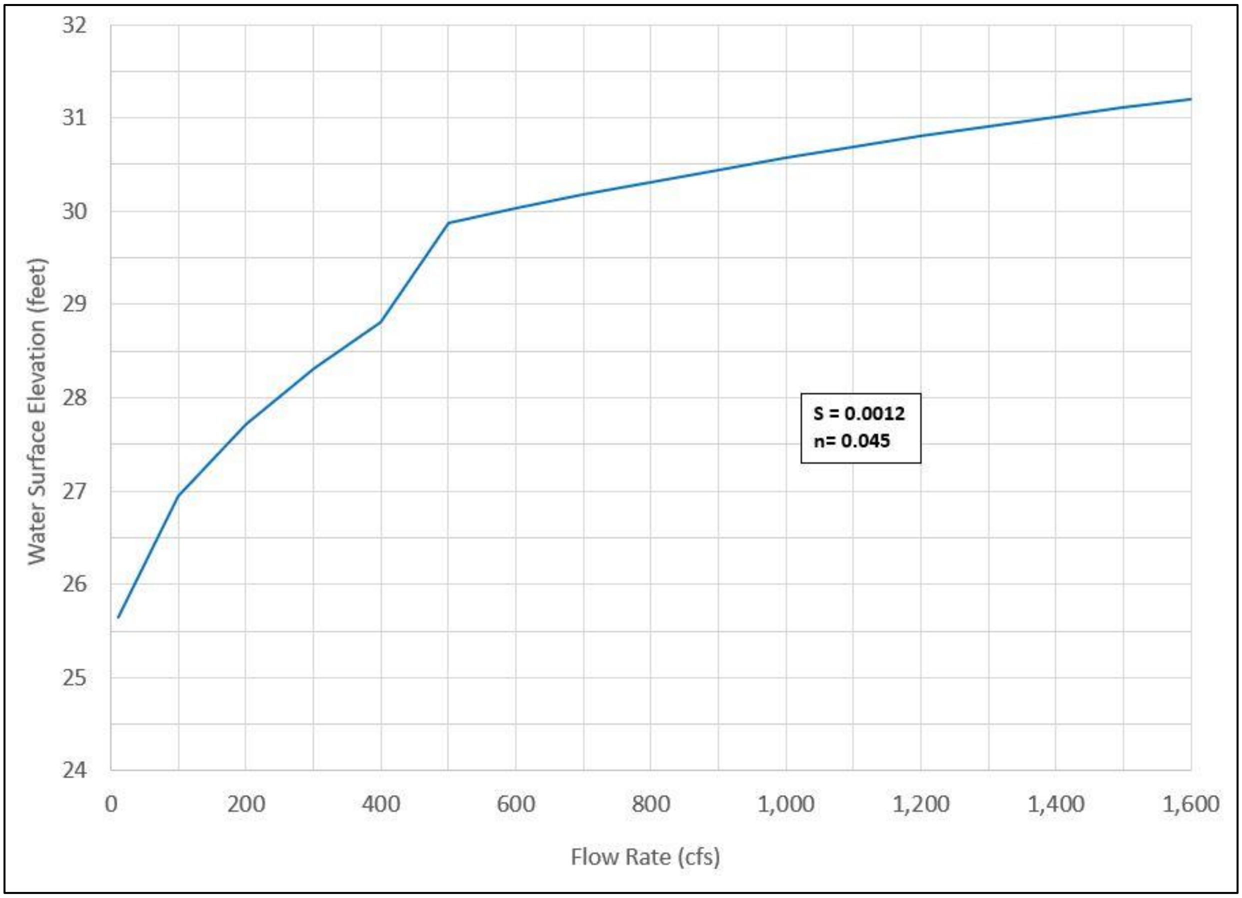


Figure 30: Downstream outflow boundary condition normal depth rating curve

5.1.5 Model Run Controls

The existing and proposed models were run as steady state flow until there was no observable change in WSE upstream or downstream of the crossing. Both existing and proposed conditions models started at time 0 hours and ended at times ranging from 16 to 48 hours with 0.5 second time steps. The amount of time required to achieve steady state was primarily dependent on the upstream and downstream boundary conditions and was similar between existing and proposed condition scenarios analyzing the same flow regimes. Due to the extensive floodplain adjacent to the unnamed tributary to Vance Creek, the smaller flow events such as the 2-year event in the unnamed tributary to Vance Creek with 100-year Chehalis River backwater effects required up to 48 hours to achieve steady state. Appendix I contains monitor point and monitor line plots showing model stability and continuity over the model run time. Both existing and proposed simulations began with a dry initial condition, and all simulations utilized the default parabolic turbulence value of 0.7.

5.1.6 Model Assumptions and Limitations

The model assumes all the basin’s flow enters the channel at the upstream boundary condition in a uniform condition even though the runoff between US 12 and the upstream boundary condition would enter the channel throughout this reach. The location of this project also requires the assumption that the floodwaters of the Chehalis River bound the mesh edges on the east and west as to not model the entire Chehalis River floodplain. The model was run in a steady-state condition. No high-water marks or other indicators were available for calibration.

5.2 Existing Conditions

The existing conditions model extended approximately 1,424 feet upstream of Culvert 125-1806W34G and 490 feet downstream of the culvert outlet past the confluence with Vance Creek. The existing model includes Culvert 125-1806W34G and a 3-foot-diameter, corrugated steel culvert in the agricultural channel 500 feet upstream of US 12. The upstream culvert was modeled as an open trench in the SRH-2D model. The upstream boundary condition was assumed to be steady state using flow inputs described in Section 5.1.4.

A combination of upstream flows in the unnamed tributary to Vance Creek with various downstream backwater effects from the Chehalis River were evaluated based on the coincidence of peak flows for each basin (Kilgore 2010). The modeling scenarios are as follows:

- 2V + LowC: 2-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 100V + LowC: 100-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 500V + LowC: 500-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 2V + 2C: 2-year peak flow in unnamed tributary to Vance Creek with 2-year Chehalis River backwater effects (steady state)
- 2V + 100C: 100-year peak flow in unnamed tributary to Vance Creek with 100-year Chehalis River backwater effects (steady state)

Although these model scenarios are run in a steady state for the peak flow, in reality there is a unique dynamic at this crossing as storm flow progress through a hydrograph. The unnamed tributary to Vance Creek normally flows from north to south until it converges with Vance Creek. However, during Chehalis River flood levels, flow reverses direction and flows south to north backwards through the crossing on the rising limb and then reverses again to flow north to south on the falling limb.

Results for the 5 steady state flow regimes analyzed under existing conditions at the locations shown in Figure 31 are summarized in Table 11. When the Chehalis River is low, Culvert 125-1806W34G creates a flow constriction that induces upstream backwater during high flows in the unnamed tributary to Vance Creek. When there is a 2-year flood in the Chehalis River backwater from the river (elevation 31.8 feet NAVD88) inundates the existing crossing and exacerbates flooding upstream of the crossing. As backwater flow from the Chehalis River increases during larger return period floods, the unnamed tributary to Vance Creek flow is dominated by the downstream conditions. Peak water surface elevations from a 100-year flood in the Chehalis River nearly overtop US 12 as shown in Figure 32.

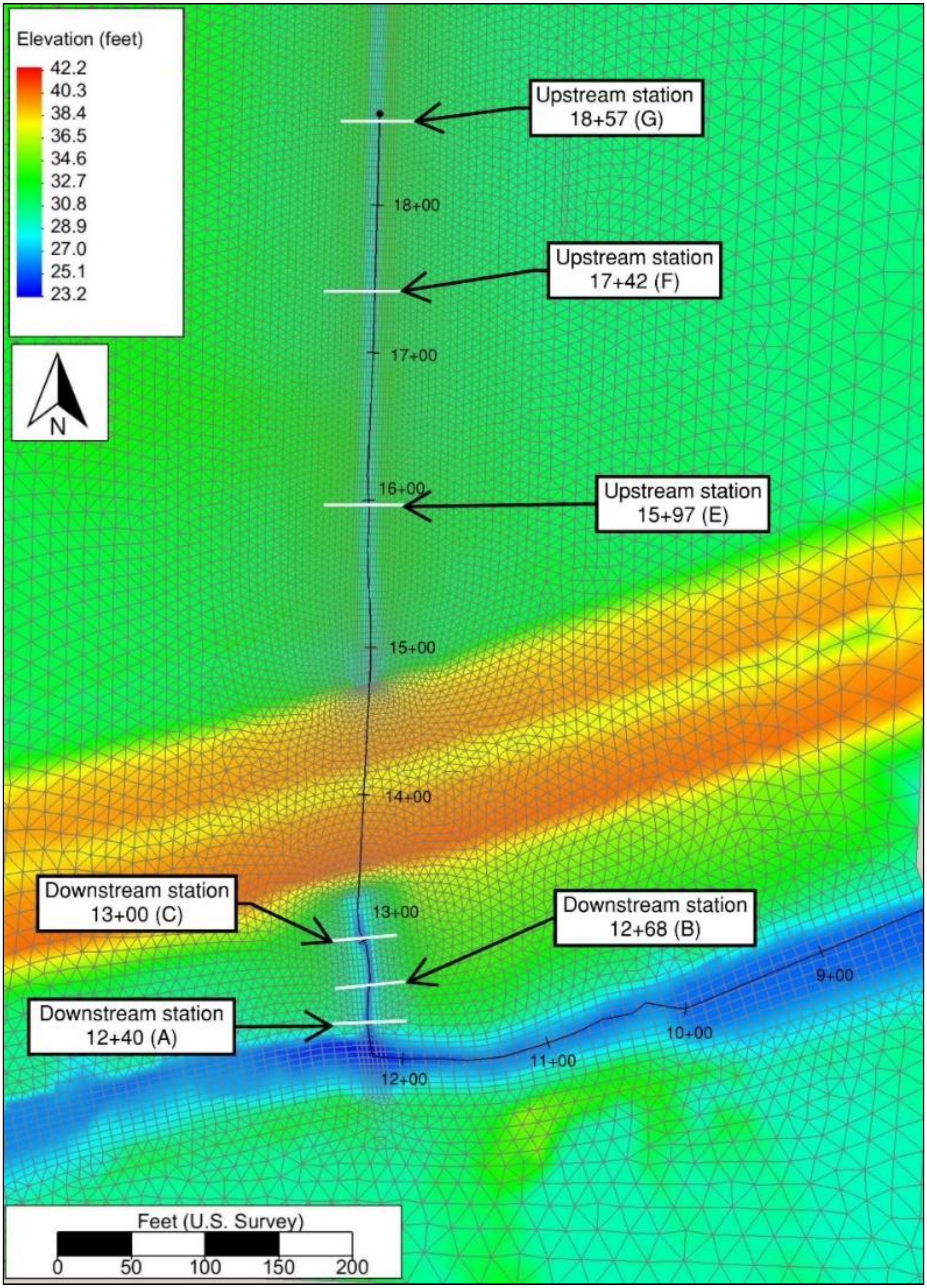


Figure 31: Locations of cross sections used for results reporting along existing stream alignment

Table 11: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year Vance, Low Flow Chehalis	100-year Vance, Low Flow Chehalis	500-year Vance, Low Flow Chehalis	2-year Vance, 2-year Chehalis	2-year Vance, 100-year Chehalis
Average WSE (ft)	DS 12+40 (A)	28.1	30.4	30.7	31.8	38.8
	DS 12+68 (B)	28.8	30.6	30.9	31.8	38.8
	DS 13+00 (C)	29.2	30.6	30.7	31.8	38.8
	Structure (D)	NA	NA	NA	NA	NA
	US 15+97 (E)	31.5	34.3	36.0	32.1	39.0
	US 17+42 (F)	32.0	34.3	36.0	32.3	39.0
	US 18+57 (G)	32.1	34.3	36.0	32.3	39.0
Max depth (ft)	DS 12+40 (A)	2.5	4.9	5.2	6.3	13.3
	DS 12+68 (B)	3.0	4.8	5.1	6.0	13.0
	DS 13+00 (C)	3.3	4.8	4.9	5.9	12.9
	Structure (D)	NA	NA	NA	NA	NA
	US 15+97 (E)	2.1	4.9	6.6	2.7	9.6
	US 17+42 (F)	3.1	5.4	7.1	3.4	10.1
	US 18+57 (G)	2.8	5.0	6.7	3.1	9.7
Average velocity (ft/s)	DS 12+40 (A)	3.4	4.5	5.0	0.7	0.3
	DS 12+68 (B)	2.3	4.7	5.3	0.7	0.3
	DS 13+00 (C)	1.6	4.2	5.6	0.9	0.4
	Structure (D)	NA	NA	NA	NA	NA
	US 15+97 (E)	3.2	0.5	0.4	2.2	0.0
	US 17+42 (F)	1.9	0.6	0.5	1.4	0.0
	US 18+57 (G)	2.1	0.9	0.7	1.8	0.0
Average shear (lb/SF)	DS 12+40 (A)	1.0	0.6	0.8	0.0	0.0
	DS 12+68 (B)	0.6	0.8	0.9	0.0	0.0
	DS 13+00 (C)	0.2	0.7	1.2	0.0	0.0
	Structure (D)	NA	NA	NA	NA	NA
	US 15+97 (E)	0.4	0.0	0.0	0.1	0.0
	US 17+42 (F)	0.1	0.0	0.0	0.1	0.0
	US 18+57 (G)	0.2	0.0	0.0	0.1	0.0

Main channel extents were approximated by modeled 2-year event water surface top widths without Chehalis River backwater effects.

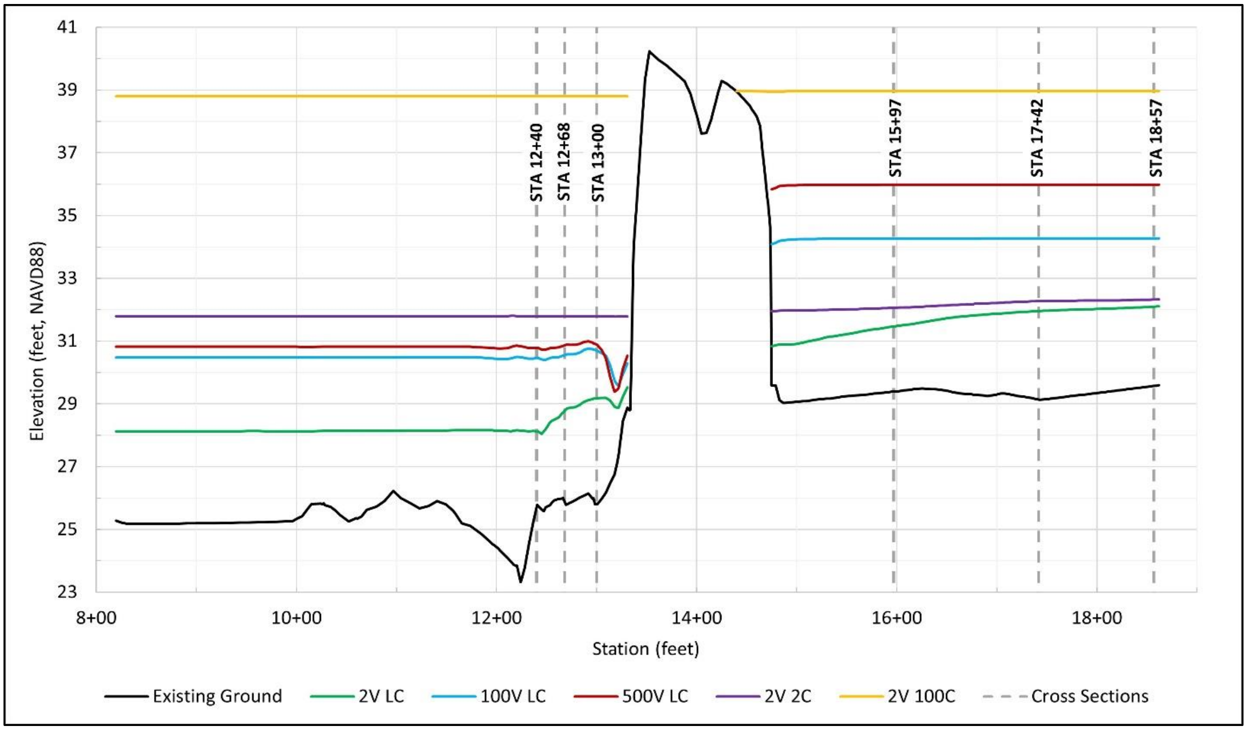


Figure 32: Existing-conditions water surface profiles

Figure 33 shows upstream WSEs for each modeled scenario. The 2-year event in the unnamed tributary does not extend into the floodplain even when there is a 2-year backwater from the Chehalis River. Flows in the unnamed tributary to Vance Creek that are higher than this are in a backwater condition and spread widely across the floodplain. Adding the influence of Chehalis River backwater spreads floodwaters even further.

The simulated flow velocities listed in Table 11 are consistent with backwater effects that have high velocities downstream and low velocities upstream. This table also shows that flooding in the Chehalis River reduces the flow velocities in the unnamed tributary upstream and downstream of the existing US 12 culvert. The highest simulated velocities occur when there is no flooding in the Chehalis River. The 100-year main channel and floodplain velocities, without Chehalis River backwater, are depicted in Figure 34 and recorded at select stations in Table 12. These data show the same pattern from backwater of high velocity flows downstream and low velocity flows upstream.

Water depth, as shown in Table 11, is also largely a function of the Chehalis River levels and backwater effects of the existing crossing. In backwater conditions caused only from the unnamed tributary flow, depths are higher upstream while downstream flow depths are more appropriate for the channel conditions. However, the presence of Chehalis River backwater elevates both the upstream and downstream flow depths.

Shear stresses at steady state again shows the typical pattern for backwatered conditions with the highest shear stress in the downstream channel and very low shear stress upstream. With the Chehalis River flooding in effect, shear stress becomes low in both the downstream and upstream reaches. Because the modeling is steady state, shear stresses that would occur during the rising and falling limbs of the Chehalis River hydrograph are not represented, but it is assumed that shear stress would be elevated during these periods.

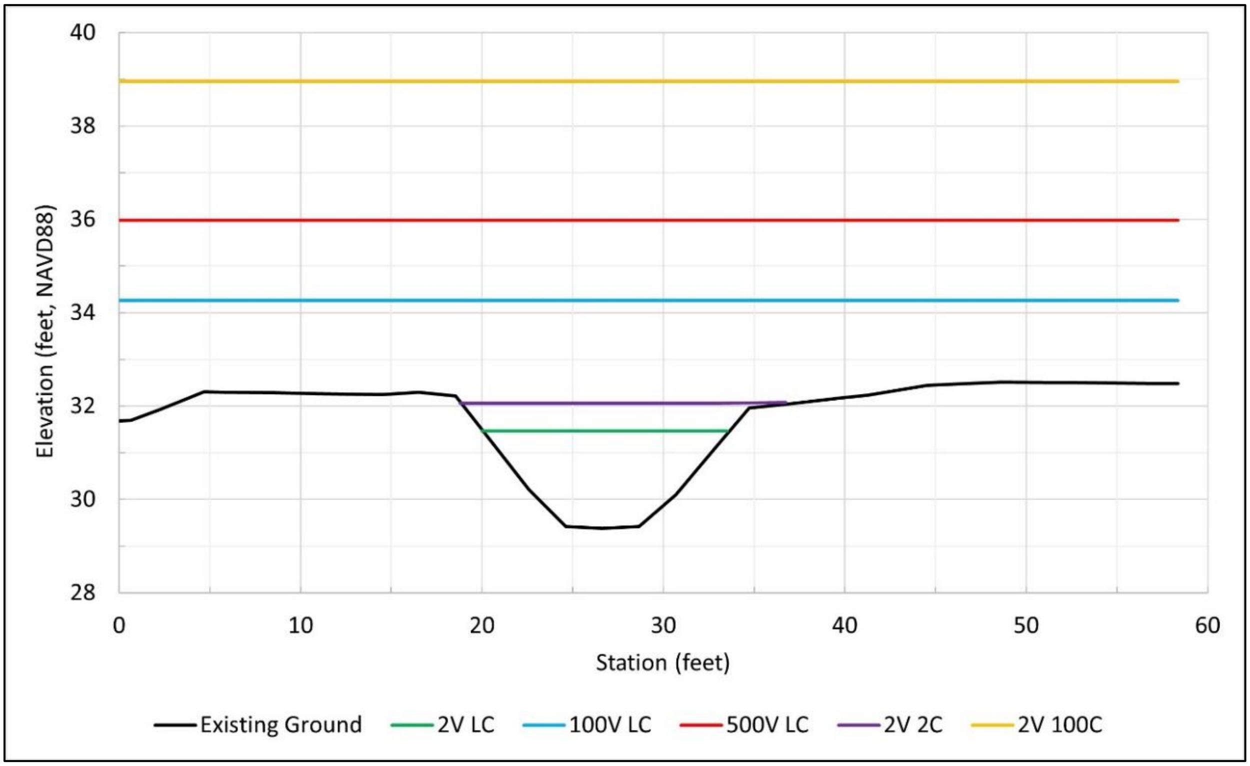


Figure 33: Typical upstream existing channel cross section (STA 15+97), looking downstream

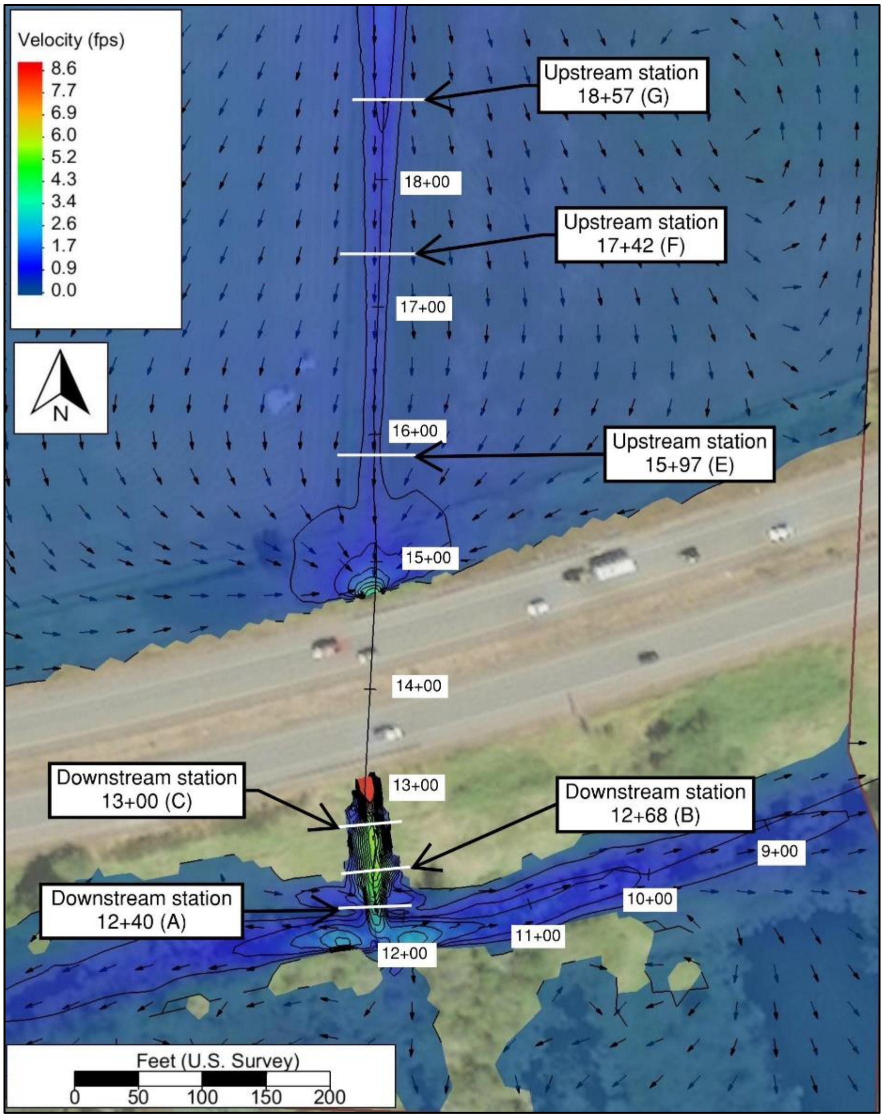


Figure 34: Existing-conditions 100-year velocity map with cross-section locations

Table 12: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 12+40	1.9	4.8	1.9
DS 12+68	2.5	5.1	2.6
DS 13+00	2.1	5.1	0.9
NA	NA	NA	NA
US 15+97	0.0	0.4	0.3
US 17+42	0.0	0.4	0.0
US 18+57	0.0	0.5	0.0

a. Right overbank (ROB) and left overbank (LOB) locations were approximated by modeled 2-year event water surface top widths without Chehalis River backwater effects.
b. Results in table correspond to model scenario without effects from Chehalis River backwater (low flow).

5.3 Natural Conditions

Natural conditions were evaluated at the PHD stage because the FUR exceeding 3.0 for the unnamed tributary to Vance Creek. Table 5 and Table 6 in Section 4.2.2 show preliminary modeled channel velocities from a location approximately 35 feet upstream from the US 12 crossing and from within the US 12 crossing were peak velocities occurred. Many different hydraulic opening widths were evaluated ranging from 17 to 60 feet.

When 2-year flood or larger event of the Chehalis River is modeled, the backwater flow in the unnamed tributary to Vance Creek is so severe that the velocity ratio through the structure is always larger than 1.0, no matter how large the hydraulic opening. When backwater from the Chehalis River is not included in modeling, a 25-foot minimum hydraulic opening consistently results in a velocity ratio close to 1.0. Based on the factors described above, a minimum hydraulic width of 25 feet was determined to be necessary to allow for natural processes to occur under current flow conditions.

5.4 Proposed Conditions: 25-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. For this crossing, a minimum hydraulic opening of 25 feet was determined to be the minimum starting point. See Section 4.2.2 for a description of how the minimum hydraulic width was determined. The hydraulic modeling emulates the vertical walls at the edge of the minimum hydraulic width.

The future conditions scenario simulated with SRH-2D modified the topography to include the proposed channel configuration, which included channel grading and the proposed secant pile bridge. With an estimated bankfull width of 12 feet the channel bed was designed with a gradually sloped 6-foot bottom width and 2H:1V side slopes. Floodplain benches were set at 10:1 slopes for 6.5 feet on both sides of the channel within the structure. The new channel profile starts approximately 102 feet upstream of the existing culvert and ends 294 feet downstream of the culvert with a constant slope of 0.63 percent.

A combination of upstream flows in the unnamed tributary to Vance Creek with downstream backwater effects from the Chehalis River were evaluated based on the coincidence of peak flows for each basin (Kilgore 2010) as follows:

- 2V + LowC: 2-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 100V + LowC: 100-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 500V + LowC: 500-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)
- 2080 100V + LowC: 2080 100-year peak flow in unnamed tributary to Vance Creek with no Chehalis River backwater effects (steady state)

- 2V + 2C: 2-year peak flow in unnamed tributary to Vance Creek with 2-year Chehalis River backwater effects (steady state)
- 2V + 100C: 100-year peak flow in unnamed tributary to Vance Creek with 100-year Chehalis River backwater effects (steady state)

Results for the six steady state flow regimes analyzed under proposed conditions at the locations shown in Figure 35 are summarized in Table 13. Figure 36 shows that the new crossing eliminates backwater effects for flows in the unnamed tributary when the Chehalis River is not flooding. When Chehalis River backwater is present the unnamed tributary is dominated by these water surface elevations. As under existing conditions, the Chehalis River floodwaters flow through the crossing in reverse (south to north) as water rises and then return to flowing north to south as flooding recedes. This backwater from a 2-year flood or larger in the Chehalis River (elevation 31.8 feet NAVD88) inundates the proposed crossing and causes flooding upstream of the crossing. Figure 37 shows a cross section of the new crossing with modeled water surface elevations.

The simulated flow velocities listed in Table 13 show that flow velocities in the unnamed tributary are similar upstream and downstream of the crossing. This supports the idea that backwater conditions related to the unnamed tributary flow are eliminated by the new crossing. When flooding from the Chehalis River is present, flow velocities are reduced. The highest simulated velocities are associated with no flooding in the Chehalis River. The 100-year main channel and floodplain velocities are depicted in Figure 38 and recorded at select stations in Table 14.

Water depth in the proposed crossing ranged from 2 feet at the 2-year flow to 4.5 feet at the 2080 100-year flow when there is no flooding from the Chehalis River. When Chehalis River flooding is present, flow depths become up to about 12 feet at the crossing.

Shear stresses follow the same pattern as velocity in that they are similar upstream and downstream of the crossing. This which confirms that backwater is not induced by the new crossing. When Chehalis River flooding is present, the shear stress becomes very low in the channel. Shear stress is highest when Chehalis River flooding is rising and flowing upstream through the crossing, and again when flooding is receding through the crossing. An agreed upon scour depth is discussed in Section 7 that recognizes that the greatest shear stresses will occur during periods of high Chehalis River flood levels when flow reverses directions and flows backwards through the crossing.

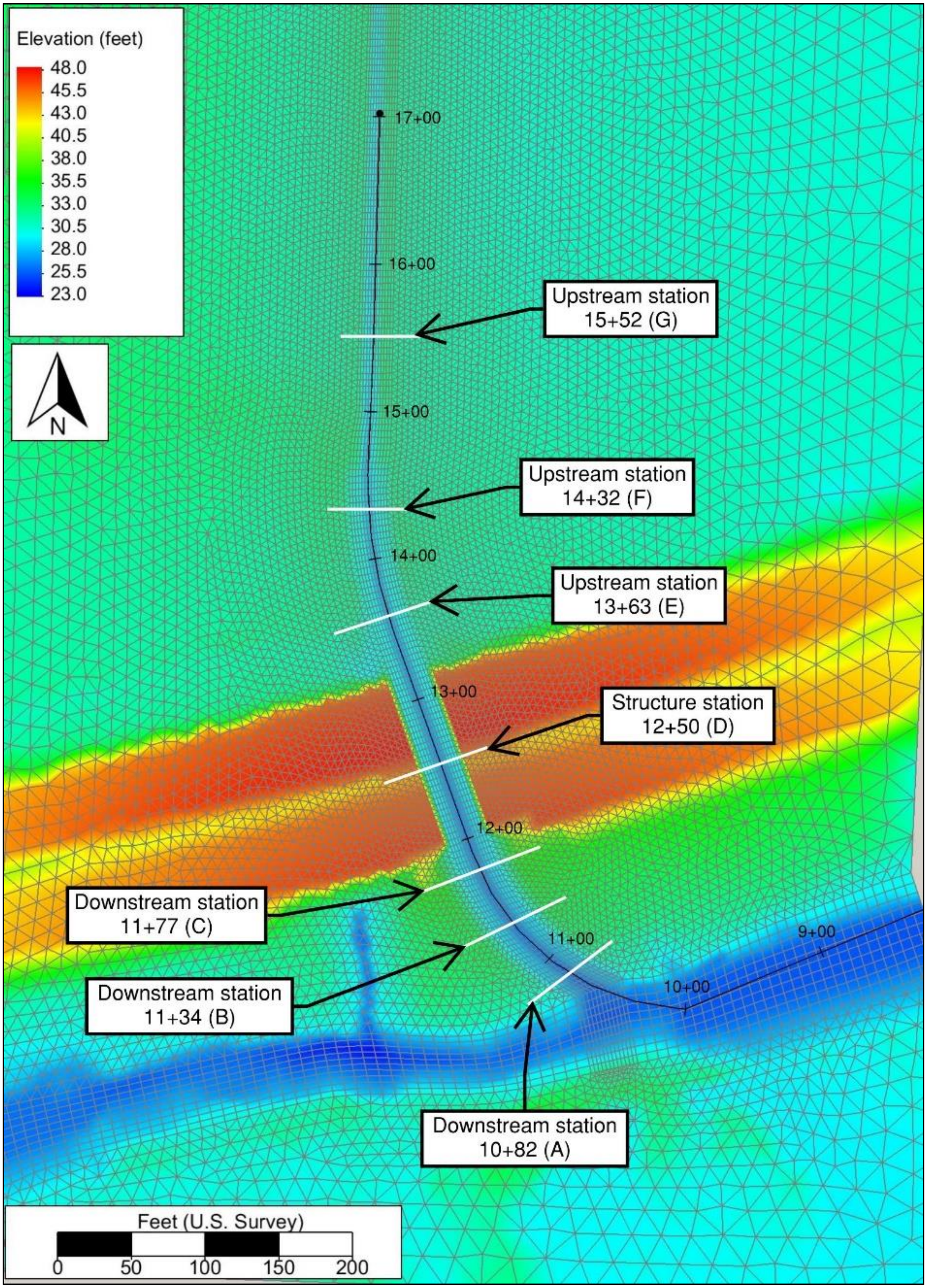


Figure 35: Locations of cross sections on proposed alignment used for results reporting

Table 13: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year Vance, Low Flow Chehalis	100-year Vance, Low Flow Chehalis	500-year Vance, Low Flow Chehalis	2080 100-year Vance, Low Flow Chehalis	2-year Vance, 2-year Chehalis	2-year Vance, 100-year Chehalis
Average WSE (ft)	DS 10+82 (A)	28.1	30.5	30.8	31.0	31.8	38.8
	DS 11+34 (B)	28.3	30.6	30.9	31.2	31.8	38.8
	DS 11+77 (C)	28.5	30.7	31.1	31.4	31.8	38.8
	Structure 12+50 (D)	29.0	30.8	31.2	31.5	31.8	38.8
	US 13+63 (E)	29.6	31.4	31.9	32.3	31.8	38.8
	US 14+32 (F)	30.0	31.5	32.1	32.4	31.8	38.8
	US 15+52 (G)	31.1	32.4	32.7	32.9	31.9	38.8
Max depth (ft)	DS 10+82 (A)	2.1	4.5	4.8	5.0	5.8	12.8
	DS 11+34 (B)	2.0	4.3	4.7	4.9	5.5	12.5
	DS 11+77 (C)	2.0	4.2	4.6	4.8	5.3	12.3
	Structure 12+50 (D)	2.0	3.8	4.2	4.5	4.8	11.8
	US 13+63 (E)	2.0	3.8	4.3	4.6	4.2	11.2
	US 14+32 (F)	2.0	3.5	4.0	4.3	3.8	10.8
	US 15+52 (G)	2.0	3.3	3.6	3.8	2.8	9.7
Average velocity (ft/s)	DS 10+82 (A)	2.0	2.8	3.3	3.6	0.5	0.1
	DS 11+34 (B)	2.5	3.1	3.6	3.9	0.6	0.2
	DS 11+77 (C)	2.6	3.5	4.0	4.3	0.7	0.2
	Structure 12+50 (D)	2.6	4.2	4.8	5.1	0.8	0.3
	US 13+63 (E)	2.6	3.1	3.1	2.9	0.9	0.1
	US 14+32 (F)	2.6	3.5	3.1	2.8	1.2	0.0
	US 15+52 (G)	3.0	2.9	2.0	1.6	2.3	0.0
Average shear (lb/SF)	DS 10+82 (A)	0.3	0.4	0.6	0.7	0.0	0.0
	DS 11+34 (B)	0.3	0.5	0.7	0.8	0.0	0.0
	DS 11+77 (C)	0.3	0.6	0.7	0.9	0.0	0.0
	Structure 12+50 (D)	0.3	0.4	0.5	0.6	0.0	0.0
	US 13+63 (E)	0.3	0.5	0.5	0.4	0.0	0.0
	US 14+32 (F)	0.3	0.4	0.3	0.2	0.0	0.0
	US 15+52 (G)	0.5	0.2	0.1	0.1	0.2	0.0

Main channel extents were approximated by modeled 2-year event water surface top widths without Chehalis River backwater effects.

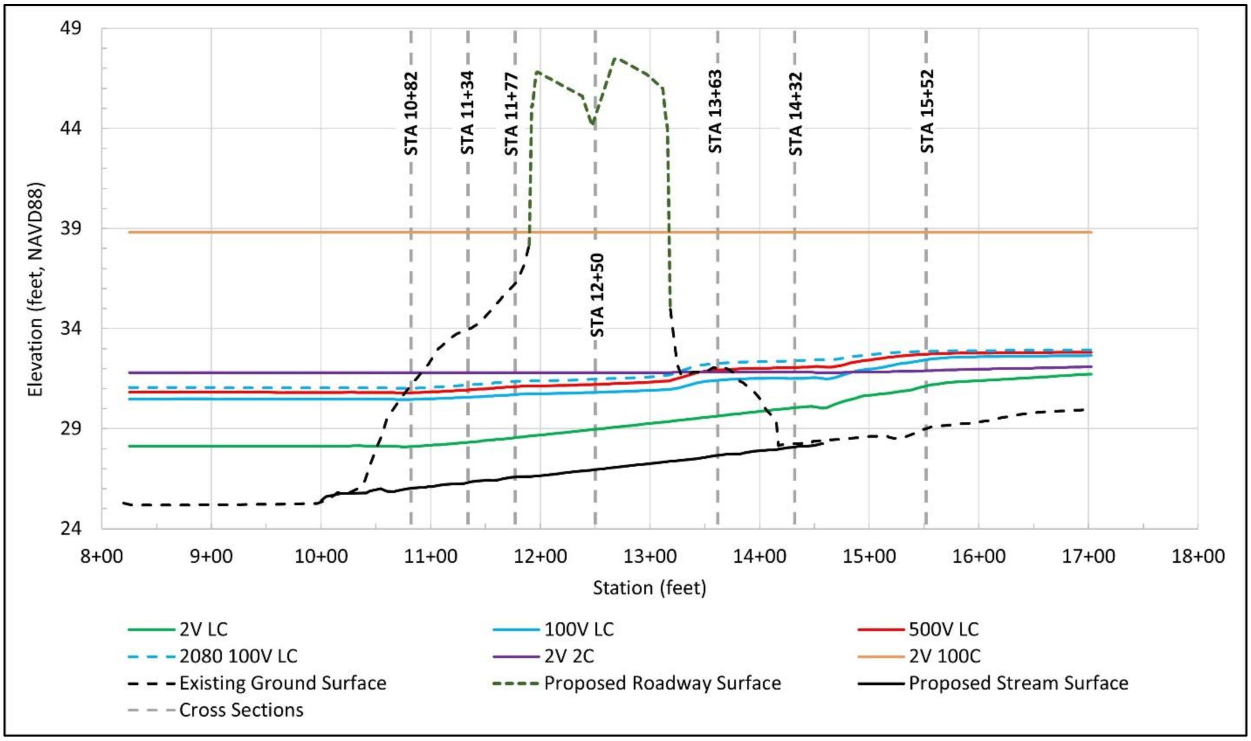


Figure 36: Proposed-conditions water surface profiles along proposed alignment

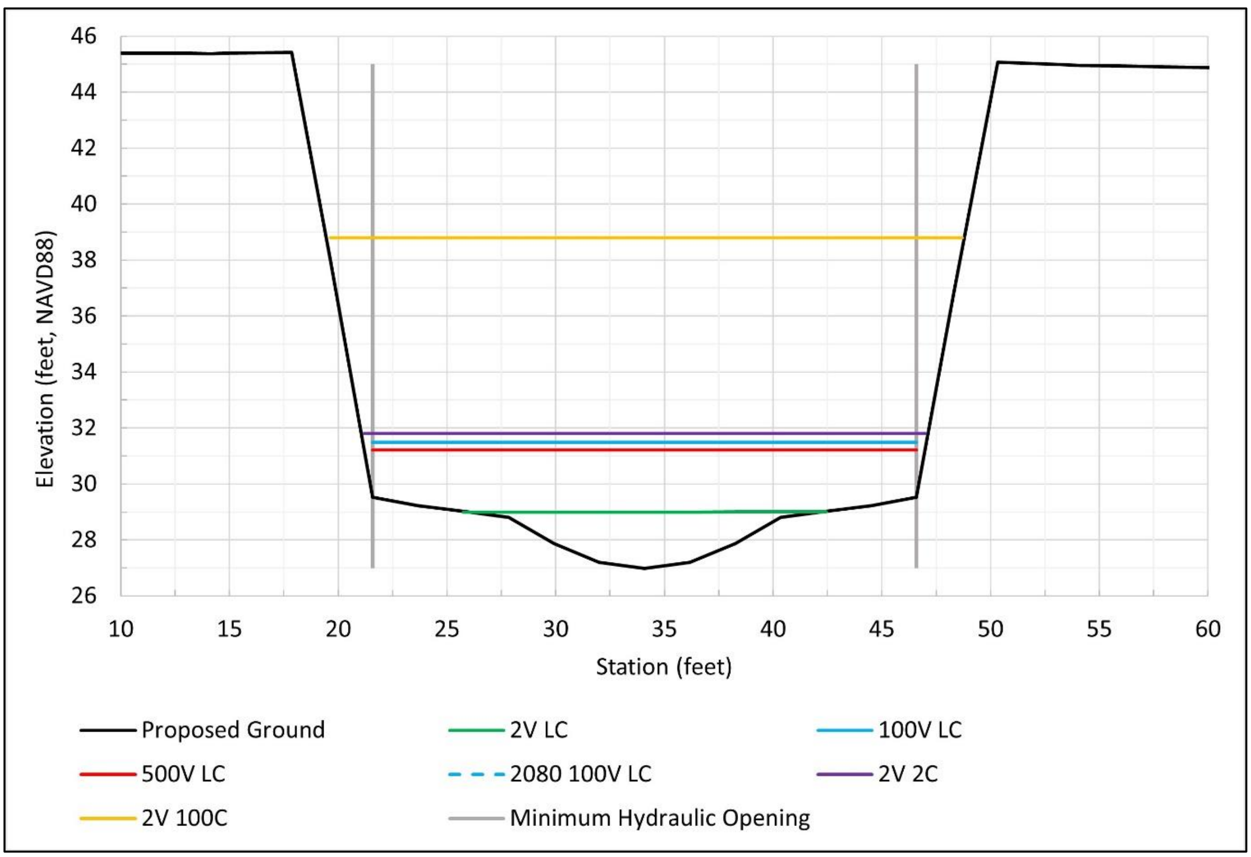


Figure 37: Typical section through proposed structure (STA 12+50), looking downstream

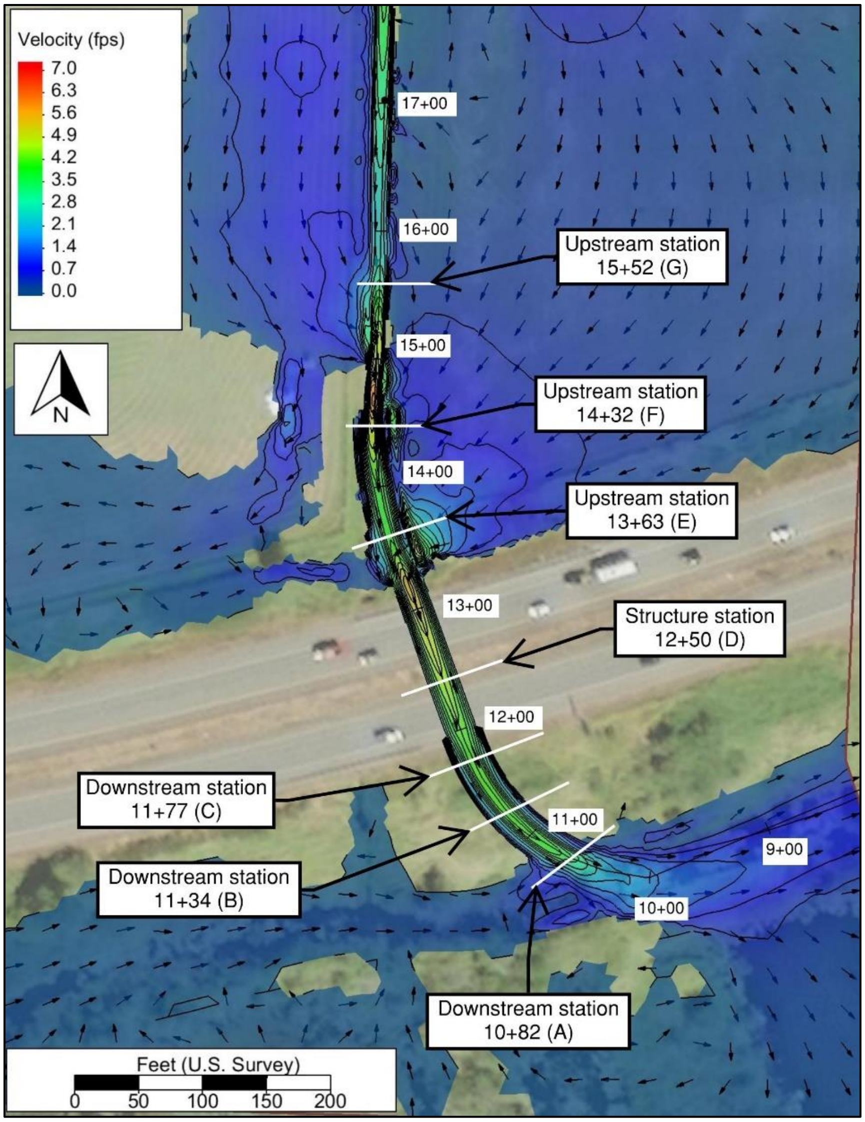


Figure 38: Proposed-conditions 100-year velocity map

Table 14: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 10+82	1.2	3.0	0.7	1.9	3.8	1.3
DS 11+34	1.5	3.4	1.6	2.5	4.2	2.5
DS 11+77	2.5	3.6	1.8	3.4	4.3	2.6
Structure 12+50	3.2	4.4	3.2	4.3	5.3	4.2
US 13+63	2.4	3.3	2.0	2.6	3.1	2.4
US 14+32	1.0	3.8	2.3	1.5	3.0	2.7
US 15+52	0.7	3.0	1.8	1.2	1.6	1.1

a. Right overbank (ROB) and left overbank (LOB) locations were approximated by modeled 2-year event water surface top widths without Chehalis River backwater effects.
b. Results in table correspond to modeled scenarios without effects from Chehalis River backwater (low flow).

6 Floodplain Evaluation

This project is within a FEMA special flood hazard area (SFHA) Zone A for the Chehalis River; see Appendix A for FIRMette. The floodplain specific to the unnamed tributary to Vance Creek is not mapped by FEMA. The existing project and expected proposed project conditions were evaluated to determine whether the project would cause a change in flood risk.

A flood risk assessment will be completed after this report has been completed.

6.1 Water Surface Elevations

The floodplain analysis was preformed using a 2-year event in the unnamed tributary to Vance Creek and 100-year Chehalis River model results because of the large influence of the Chehalis around the crossing.

The proposed design is not expected to change the mapped FEMA SFHA. The Zone A designation of this floodplain indicates that the floodplain boundaries were derived based on topography from USGS topographic maps. The boundaries for Zone A floodplains are not typically determined with a level of detail that includes fill prisms from roads and highways such as US 12. So, even though US 12 restricts Chehalis River flooding north of the highway, it is not part of FEMAs considered floodplain hydraulics. Therefore, any changes to US 12 will not cause change in the SFHA.

Although the proposed design will not impact FEMA mapping, the larger hydraulic opening will allow water to flow more freely across the highway. This will help eliminate backwater and slightly lower the water surface elevation in the upstream reach (see

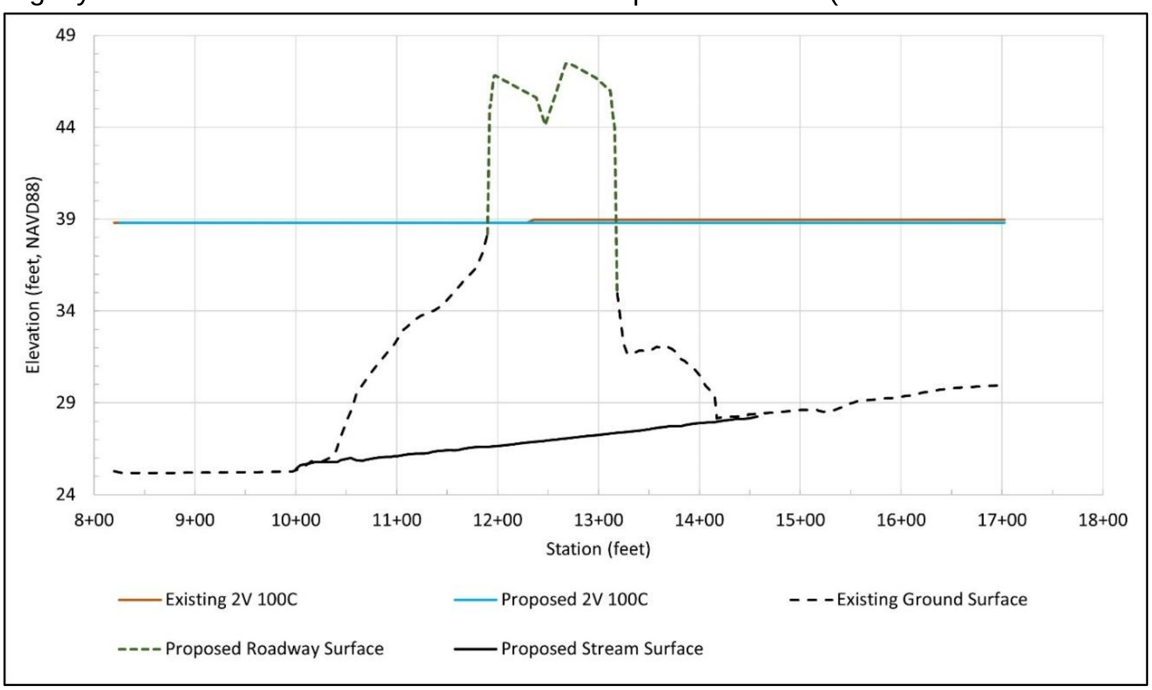


Figure 39 and Figure 40). The “Became Dry” green border around the boundary of the model shown in Figure 40 is due variability in the model boundary computations that have higher inaccuracy. It is known that the Chehalis floodplain extends far to the east and west of the model boundaries and would, therefore, not become dry under proposed conditions. Similarly, slight changes in the WSE or mesh element size on the edges of the floodwaters, such as around the water treatment facility located in the northern portion of Figure 40, may show areas becoming wet or dry at a level of detail less accurate than the model can predict. As such, the floodplain around the water treatment facility is predicted to decrease in WSE, so areas shown in Figure 40 as becoming wet around the water treatment facility are not represented accurately.

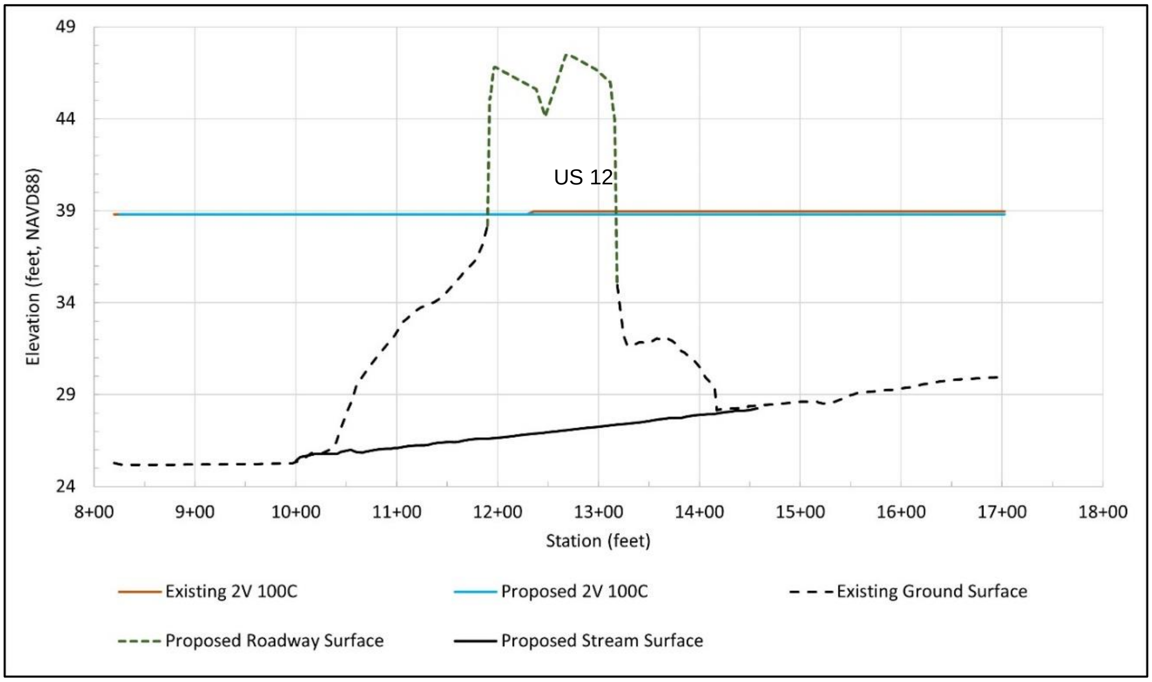


Figure 39: Existing and proposed conditions water surface profile comparison for 2-year Unnamed Tributary to Vance Creek flow during 100-year Chehalis River flow

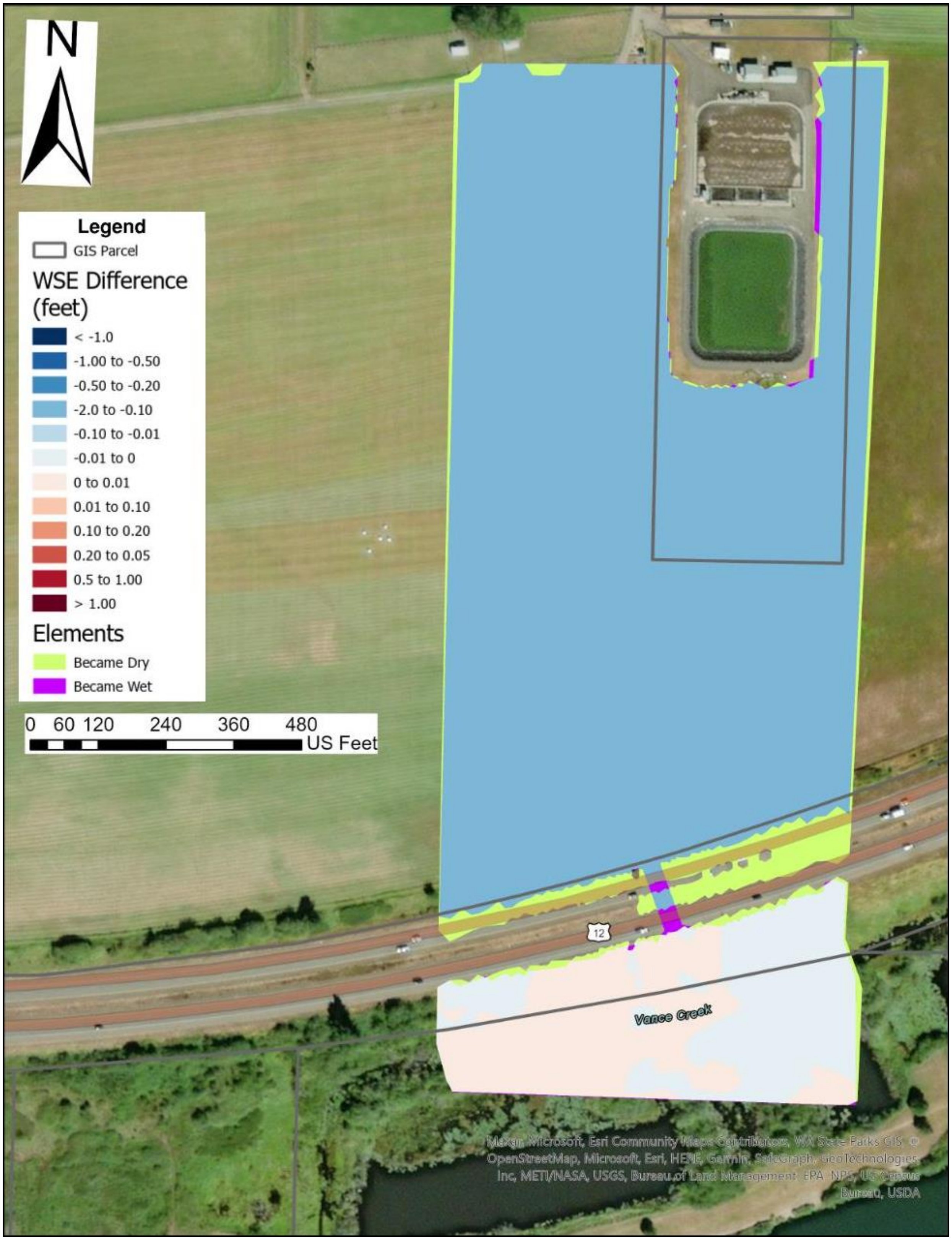


Figure 40: 2-year Unnamed Tributary to Vance Creek and 100-year Chehalis River water surface elevation change from existing to proposed conditions

7 Final Scour Analysis

For this FHD, the risk for lateral migration, potential for long-term degradation, and evaluation of total scour are based on the final geotechnical report dated February 2, 2020.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended final structure, and considering the potential for lateral channel migration, final scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The WCDG require that structures account for lateral channel movement that can occur in their design life and that the design channel maintains floodplain continuity. The unnamed tributary to Vance Creek is a straight channel that flows between agricultural fields. Further upstream the channel is armored in the City of Elma. Because this channel is artificially constrained, the risk of channel migration is minimal and, therefore, the risk to the structure due to lateral channel migration both upstream and through the structure is limited.

7.2 Long-term Degradation of the Channel Bed

Long-term changes to streambed elevations associated with man-made or natural causes are considered long-term aggradation and degradation. Aggradation is the deposition of material upstream of a crossing caused by erosion of the channel and/or upstream watershed. Aggradation is not a component of total scour. Conversely, degradation is the lowering or scouring of the channel bed across long reaches of channel caused by a decrease in the sediment supply from upstream and/or removal of a grade control feature in the channel downstream of the road crossing. Degradation is a component of total scour.

The proposed design closely mimics the upstream channel shape and gradient. Therefore, the transport capacity of the channel within the project reach will closely mimic the transport capacity of the channel upstream of the project. However, there is some sediment upstream that has likely built up because of the undersized existing culvert. The new crossing will allow this material to be transported downstream and the channel gradient to level out. At this sediment adjusts over time, there is the potential for the channel elevation within the crossing to decrease about 0.5 foot as shown in Figure 41. This assumes that the land cover and watershed land use characteristics will remain relatively constant during the life of the new structure.

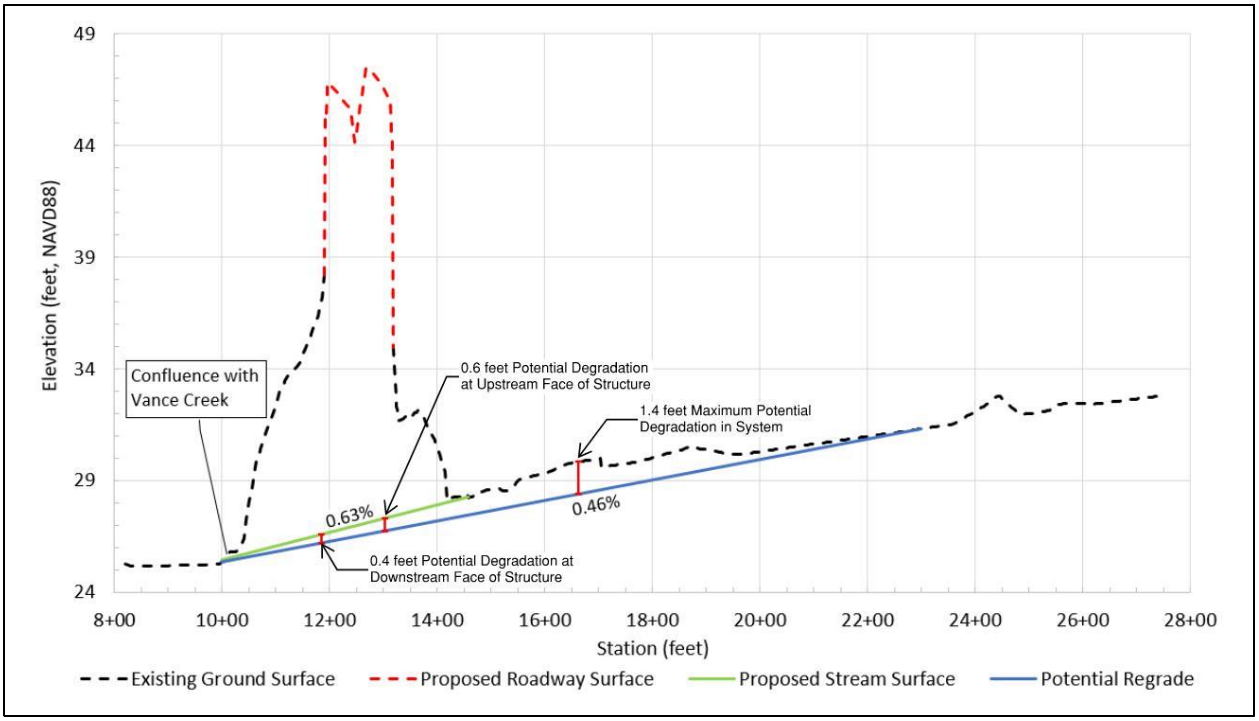


Figure 41: Potential long-term degradation at the proposed structure

7.3 Contraction Scour

Contraction scour is the lowering of the streambed elevation associated with a constriction of flow through a culvert or bridge. The scour condition is dependent on the transport of bed material in flow upstream of a bridge or culvert. Clear-water scour occurs when there is insufficient flow velocity to transport bed material, while live-bed scour occurs when there is transport of bed material from an upstream reach into the crossing. The prevailing scour condition is determined by calculating the critical velocity of the D50 and comparing it to the mean flow velocity modeled upstream of the crossing.

The most significant contraction scour is associated with backwater flow from the Chehalis River flood flows. Contraction scour calculations that account for Chehalis River flooding were conducted for the preliminary scour analysis (PSA) during early stages of design. The combination of approximately the 100-year flood event in the Chehalis River (as simulated by the most recent Chehalis River basin hydraulic model available at the time of the PSA) and a 2-year flow in the unnamed tributary to Vance Creek was found to represent the “worst-case” flow condition for scour analysis.

The resulting live-bed scour condition estimated over 30 feet of scour at the US 12 crossing. There are several reasons to believe that this is an overestimate, most importantly that the proposed crossing is only 25 feet wide. Geotechnical data for the project indicates that the material at this depth consists of medium dense to very dense silty sand with gravel. If over 30 feet of scour occurred at this site, there would be complete removal of soil material to this depth through the crossing, which would severely damage the highway. Nowhere near that kind of damage has occurred along this section of the highway in past river flood events, though far less flow passes through the existing culvert. Numerical modeling suggests that the duration of maximum flow velocity during a receding 10-year river flood event would be extremely short (on the order of minutes) and unlikely to scour away 30 feet of material in that time.

After the completion of the PSA, the design team and comanagers discussed on November 17th, 2021 in the Design Review Meeting for the Grays Harbor County Fish Barriers – Remove Fish Barriers project, that the initial estimates of scour are likely an overestimation due to predicted scour estimates based on HEC-18 assuming instantaneous scour. In reality scour occurs over a longer period of a flood event, or several flood events. The proposed design also has built in scour resistance to sustain its low flow channel shape during short term periods of flood flows through the opening. It was also discussed in the November 17th meeting that the Natural Systems Design (NSD) independent review of the hydraulic model noted the model may have included conservative assumptions that increase the predicted velocities corresponding scour at the crossing. During the November 29th, 2021 Grays Harbor Project – Vance & Wenzel Structure Types meeting, it was determined that 15 feet of scour was a better, yet still conservative, estimate for scour depth occurring during Chehalis 500-year event. This 15-foot depth is, therefore, used for design of this crossing.

The adopted scour estimate of 15 feet accommodates the expected 1.4 feet of local scour that may occur near the outlet of the structure. It also provides an allowance for the design to remain stable if the channel experiences a combination of hydraulic forces that favor streambed particle mobilization. The hydraulic modeling completed to analyze the crossing was limited to a focused project area and made assumptions about the boundary conditions on the edges of the model domain. These boundary assumptions confined water to a smaller area than may likely occur in the complex floodplain of the Chehalis River, overestimating the depth and duration of flood waters entering the crossing during a flood, and exiting the crossing during following a backwater event. These overestimated flood elevations in the hydraulic model, lead to deeper estimates of scour when calculated using standard engineering practices. It is expected that water surface elevations would find other openings in the US 12 road prism and would potentially overtop lower elevation portions of the road during large flood events. This real-world potential would reduce actual hydraulic forces focused on the crossing. Using the model results that calculate conservative results provide a design the errs toward a flood resilient crossing that can withstand larger flood events, improving safety for the traveling public. Additionally, more investigation into the geotechnical subsurface conditions indicate the likelihood that the finer streambed materials that would easily scour are sitting atop a much more resistant glacial outwash layer at depths approximately 7 to 10 feet below ground surface.

Considering the estimated local scour, the conservative hydraulic modeling, the likelihood of the crossing seeing hydraulic pressure relief from other adjacent culvert crossings outside the study area of the crossing, and the apparent depth of the glacial outwash layer, adopting a design scour depth of 15 feet remains conservative, and more refined than relying on a single estimate from the HEC-18 method that was not informed by the context of the project site. Applying professional engineering judgement, the depth of estimated scour for this crossing is set at 15 feet. This depth accommodates the potential for hydraulic forces to scour the top layer of native and placed streambed materials, as well as allowing for some reduced potential scouring of the more scour resistant glacial outwash sublayer 7 to 10 feet below the surface. 15 feet acknowledges varying scour potential and fits the calculated estimates to the context of the site conditions.

7.4 Local Scour

Local scour includes scour due to acceleration of flow and resulting vortices induced by specific features such as piers, spurs, and embankments. The following sections describe the local scour analysis methodology and results of the local scour components.

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was not quantified at the crossing because the proposed abutments are located outside the extents of the proposed 500-year floodplain of the unnamed tributary. Potential scour associated with Chehalis River backwater event is included in the decision to address a potential 15 feet of contraction scour.

7.4.3 Bend Scour

There are two subtle bends in the stream alignment in the project reach. Only the bend on the downstream end of the culvert was evaluated for bend scour associated with flow in the unnamed tributary. The bend upstream of the culvert has an extremely large radius of curvature, so bend scour calculations would be insignificant.

Bend scour was calculated following the methodology outlined in HEC-23 (Lagasse et al. 2012). Depth of bend scour was estimated using Maynord's method. The analysis indicates that the depth of bend scour is 1.3 feet during the 2-year unnamed tributary to Vance Creek and Low Chehalis event. See Appendix K for detailed calculations. Given the location of the bend and distance downstream from the culvert, it will not extend into the opening of the new structure, so it is not included as contributing to the scour potential at the structure.

7.5 Total Scour

Total scour includes the three components previously discussed: long-term degradation, contraction scour, and local scour. These three components are added to obtain the total scour.

Total depths of scour for the scour design flood and scour check flood at the proposed unnamed tributary to Vance Creek bridge as shown in the construction plans, are provided in Table 15. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 15.

Table 15: Scour analysis summary

Calculated Scour Components and Total Scour for US 12 Unnamed Tributary to Vance Creek		
	Scour design flood	**Scour check flood**
Long-term degradation (ft)	**0**	**0**
Contraction scour (ft)	N/A	N/A
Local scour (ft)[a]	N/A	N/A
Total depth of scour (ft)	**15**	15

a. Bend scour occurs outside the limits of the new bridge so is not included as part of the scour that could affect the structure.

8 Scour Countermeasures

Scour countermeasures were designed and evaluated utilizing guidance outlined in Bridge Scour and Stream Instability Countermeasures Hydraulic Engineering Circular No. 23 3rd Edition (HEC-23) (Lagasse et al., 2009) to assist in the protection of the proposed unnamed tributary to Vance Creek structure, walls, and roadway embankment as shown in the final plans. Calculations (Appendix M) for each method were based on channel hydraulics modeled utilizing SRH-2D as described in Section 5.

The secant bridge piles will extend below the anticipated scour depth. Additionally, meander bars are included in the design to reduce channel entrapment and scour, as the proposed meander bar material has limited mobility at high flows, as discussed in Section 4.3.1. Finally, buried below 2 feet of native streambed sediment in the proposed channel, a coarse mix is proposed, as discussed in Section 4.3.1. This sediment will be layered in 1-foot lifts with slash material to consolidate the matrix to resist scour. The details of the meander bars and coarse sediment layers can be found in Appendix D.

9 Summary

Table 16 presents a summary of the results of this PHD Report.

Table 16: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	23,937 LF	2.1 Site Description
Bankfull width	Reference reach found?	No	2.7.1 Reference Reach Selection
	Design BFW	12.0 ft	2.7.2 Channel Geometry
	Concurrence BFW	12.0 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	See link	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	See link	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	247 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	383 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	No	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	Yes	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	0.39%	2.6.2 Existing Conditions
	Reference reach	N/A	2.7.1 Reference Reach Selection
	Proposed	0.63%	4.1.3 Channel Gradient
Hydraulic width	Existing	8 ft	2.6.2 Existing Conditions
	Proposed	25 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	151 ft	2.6.2 Existing Conditions
	Proposed	128 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Bridge	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	3	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Boulder clusters	0	4.3.2 Channel Complexity
	Coarse bands	0	4.3.2 Channel Complexity
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	Yes	6 Floodplain Evaluation
	Lateral migration	Yes	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Final Scour Analysis
	Scour countermeasures	Yes	8 Scour Countermeasures
Channel degradation	Potential?	No	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	No	7.2 Long-term Degradation of the Channel Bed

References

Aquaveo. 2021. SMS Version 13.1.14.

Arneson, L.A., L.W. Zevenbergen, P.F. Lagasse, P.E. Clopper. 2012. Evaluating Scour at Bridges—Fifth Edition. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-HIF-12-003 (HEC No. 18).

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Chow, V.T. 1959. Open Channel Hydraulics, McGraw-Hill Book Company, New York.

Fox, Martin and Bolton, Susan. 2007. *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management.* Vol. 27, Issue 1. Pg. 342–359.

Lagasse, P.F., P.E. Clopper, J.E. Pagan-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard. 2009. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance—Third Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-NHI-09-111.

Kilgore, R.T., D.B. Thompson, and D.T. Ford, D.T. 2010. Estimating Joint Probabilities of Design Coincident Flows at Stream Confluences. Transportation Research Board. National Cooperative Highways Research Program. NCHRP Report 15-36.

PRISM Climate Group, 2021, Oregon State University. Online at https://prism.oregonstate.edu/normals/. Accessed on date unknown.

USBR. 2017. SRH-2D Version 3.3.0.

USGS (United States Geological Survey). 2016. The StreamStats program, online at http://streamstats.usgs.gov. Accessed on date unknown.

WDFW. 2015. Washington State Fish Passage. Website accessed online: https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WSDOT (Washington State Department of Transportation). 2022a. *Hydraulics Manual*. Olympia, Washington. Publication M 23-03.07.

WSDOT. 2022b. *Standard Specifications for Road, Bridge, and Municipal Construction*. Olympia, Washington. Publication M 41-10.

Appendices

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

123°25'42"W 46°59'58"N

123°25'4"W 46°59'33"N

Feet 0 250 500 1,000 1,500 2,000

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- B 20.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

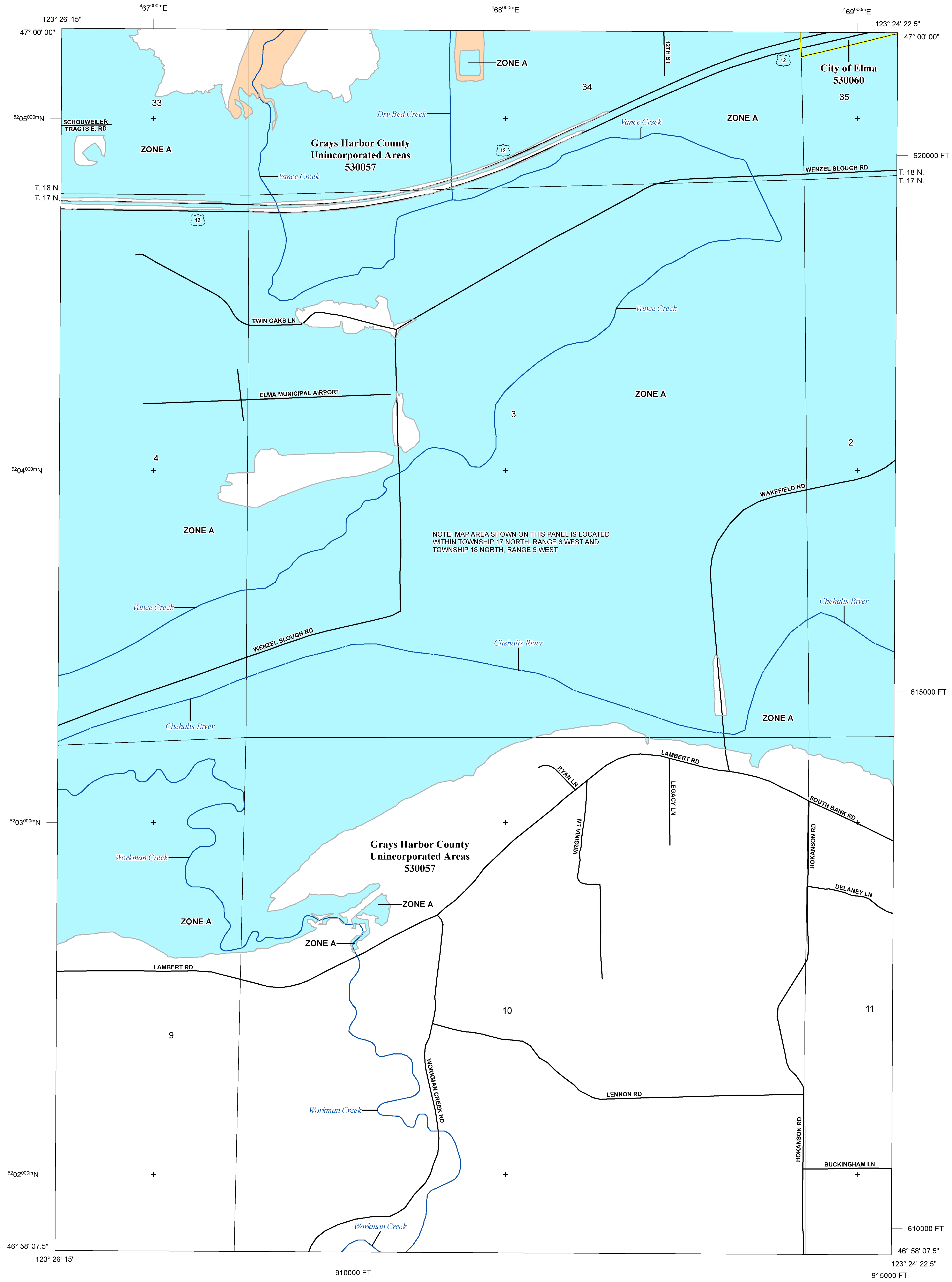
N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 5/13/2022 at 12:50 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.



FLOOD HAZARD INFORMATION

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT

HTTPS://MSC.FEMA.GOV

SPECIAL FLOOD HAZARD AREAS	Without Base Flood Elevation (BFE) *Zone A, V, A99*
	With BFE or Depth *Zone AE, AO, AH, VE, AR*
	Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD	0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
	Future Conditions 1% Annual Chance Flood Hazard *Zone X*
	Area with Reduced Flood Risk due to Levee See Notes. *Zone X*
	Area with Flood Risk due to Levee *Zone D*
OTHER AREAS	NO SCREEN Area of Minimal Flood Hazard *Zone X*
	Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES	Channel, Culvert, or Storm Sewer
	Levee, Dike, or Floodwall
	E 18.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
	8 Coastal Transect
	Coastal Transect Baseline
	Profile Baseline
	Hydrographic Feature
	513 Base Flood Elevation Line (BFE)
OTHER FEATURES	Limit of Study
	Jurisdiction Boundary

NOTES TO USERS

For information and questions about this Flood Insurance Rate Map (FIRM), available products associated with this FIRM, including historic versions, the current map date for each FIRM panel, how to order products, or the National Flood Insurance Program (NFIP) in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Flood Map Service Center website at https://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Flood Map Service Center at the number listed above.

For community and countywide map dates refer to the Flood Insurance Study Report for this jurisdiction.

To determine if flood insurance is available in the community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

Base map information shown on this FIRM was provided in digital format by the Washington Department of Transportation dated 6/15/2017, the U.S. Census Bureau TIGER files dated 6/1/2016 and the Federal Emergency Management Agency effective Flood Insurance Study spatial files dated 2/3/2017.

SCALE

N

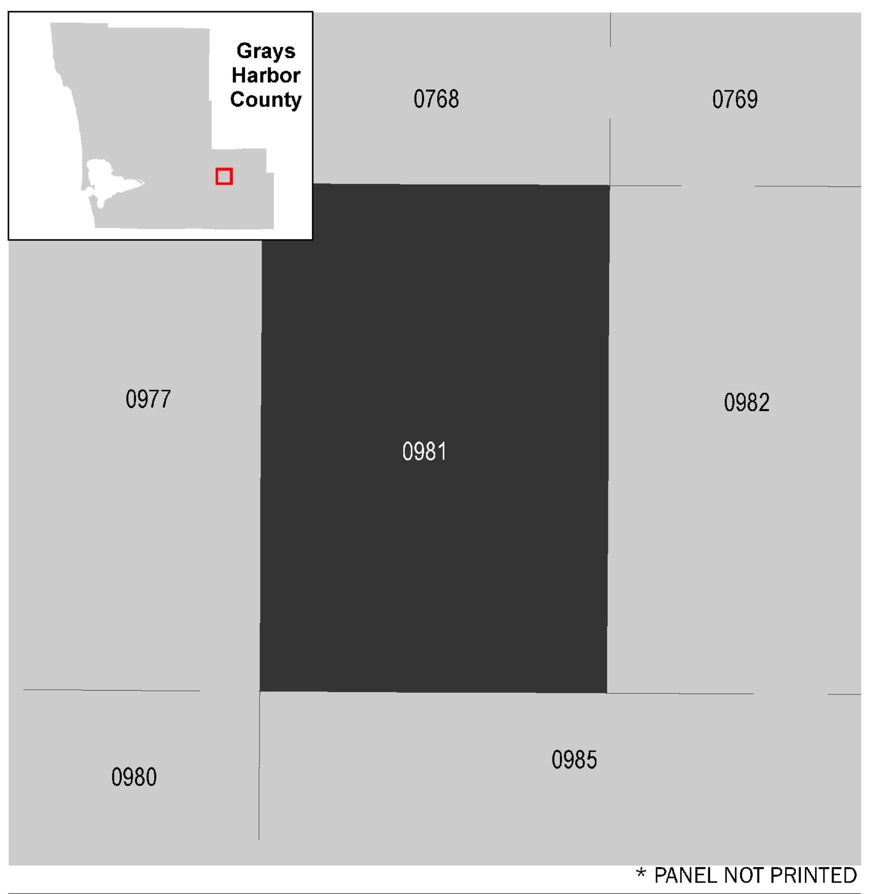
Map Projection:
NAD 1983 UTM Zone 10N;
Western Hemisphere; Vertical Datum: NAVD 88

1 inch = 500 feet 1:6,000

0 500 1,000 2,000 feet

0 125 250 500 meters

PANEL LOCATOR



* PANEL NOT PRINTED

FEMA
National Flood Insurance Program

NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP

GRAYS HARBOR COUNTY, WASHINGTON
And Incorporated Areas

PANEL **981** OF **1295**

FEMA

Panel Contains:

COMMUNITY	NUMBER	PANEL	SUFFIX
ELMA, CITY OF	530060	0981	E
GRAYS HARBOR COUNTY	530057	0981	E

VERSION NUMBER
2.3.3.5

MAP NUMBER
53027C0981E

MAP REVISED
SEPTEMBER 18, 2020

Appendix B: Hydraulic Field Report Form (Not Used)

(A Hydraulic Field Report Form was not generated for this site)

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	Grays Harbor - Vance Creek
By:	Karen Comings, P.E.

Design Gradation:

Location:	Proposed Channel			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.33	0.23	0.12	0.03
in	4.00	2.70	1.40	0.35
mm	102	69	35.6	8.9

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Design Gradation:

Location:				
	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				88.0
2.5	63.5	100	65	54	37	32	28				79.0
2.0	50.8	92.5	50	45	29	25	22				67.0
1.5	38.1	79	35	32	21	18	16				52.7
1.0	25.4	66	20	18	13	12	11				38.4
0.50	12.7	48	5	5	5	5	5				22.2
0.19	4.75	29									11.6
0.02	0.425	10									4.0
0.003	0.0750	5									2.0
% per category		40	60	0	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		40.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

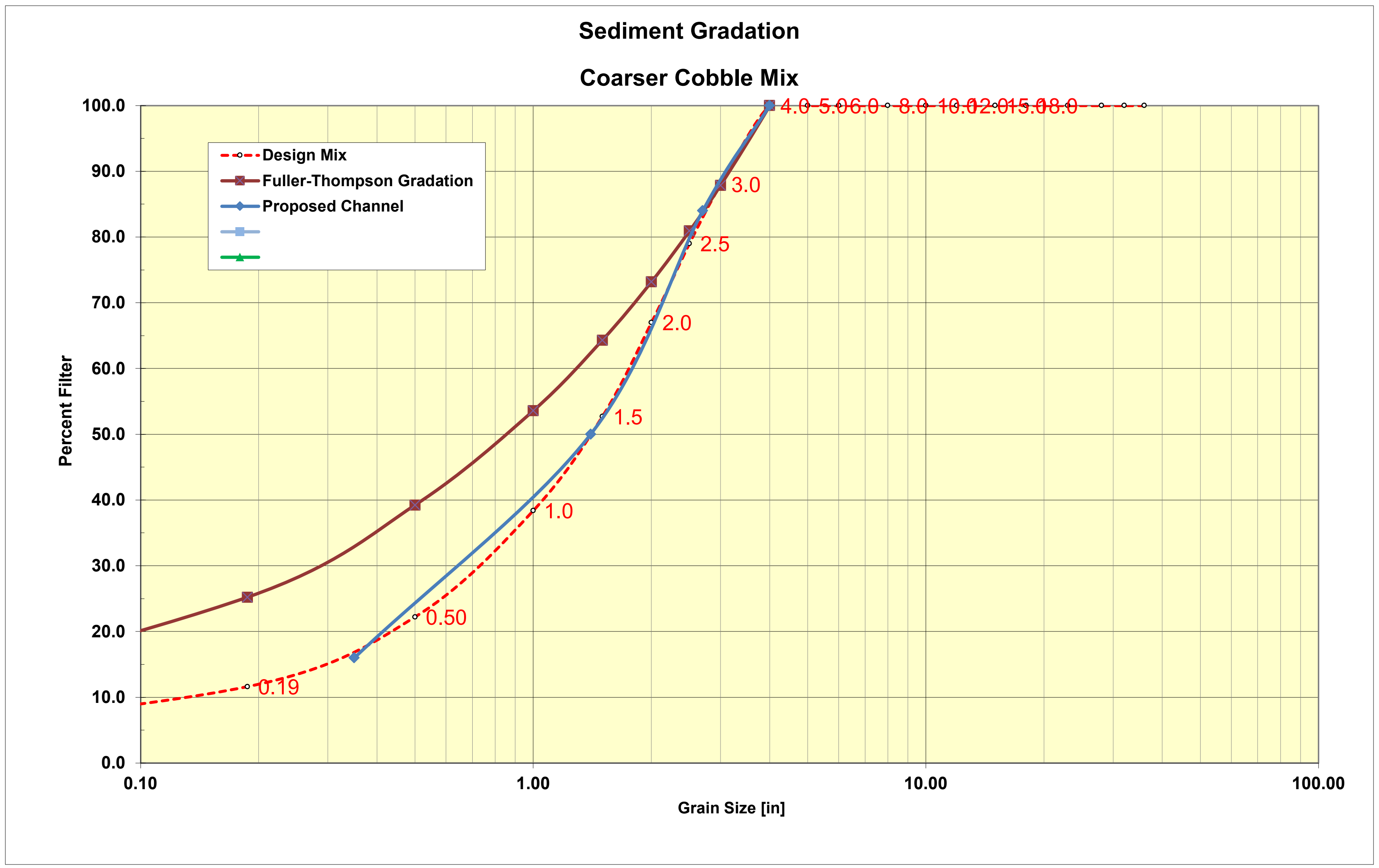
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.052	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	100-Year	2080 100-Year	500-Year		
Average Modeled Shear Stress (lb/ft^2)	0.91	2.10	2.36	2.10		
τ_{ci}						
2.61	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.52	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.42	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.28	No Motion	No Motion	Motion	No Motion	No Motion	No Motion
2.12	No Motion	No Motion	Motion	No Motion	No Motion	No Motion
2.01	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.88	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.78	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.66	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.53	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.44	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.35	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.24	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.17	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.10	No Motion	Motion	Motion	Motion	No Motion	No Motion
1.01	No Motion	Motion	Motion	Motion	No Motion	No Motion
0.89	Motion	Motion	Motion	Motion	No Motion	No Motion
0.72	Motion	Motion	Motion	Motion	No Motion	No Motion

D50	2.70	in
	0.23	ft
	68.6	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Fuller-Thompson Gradation

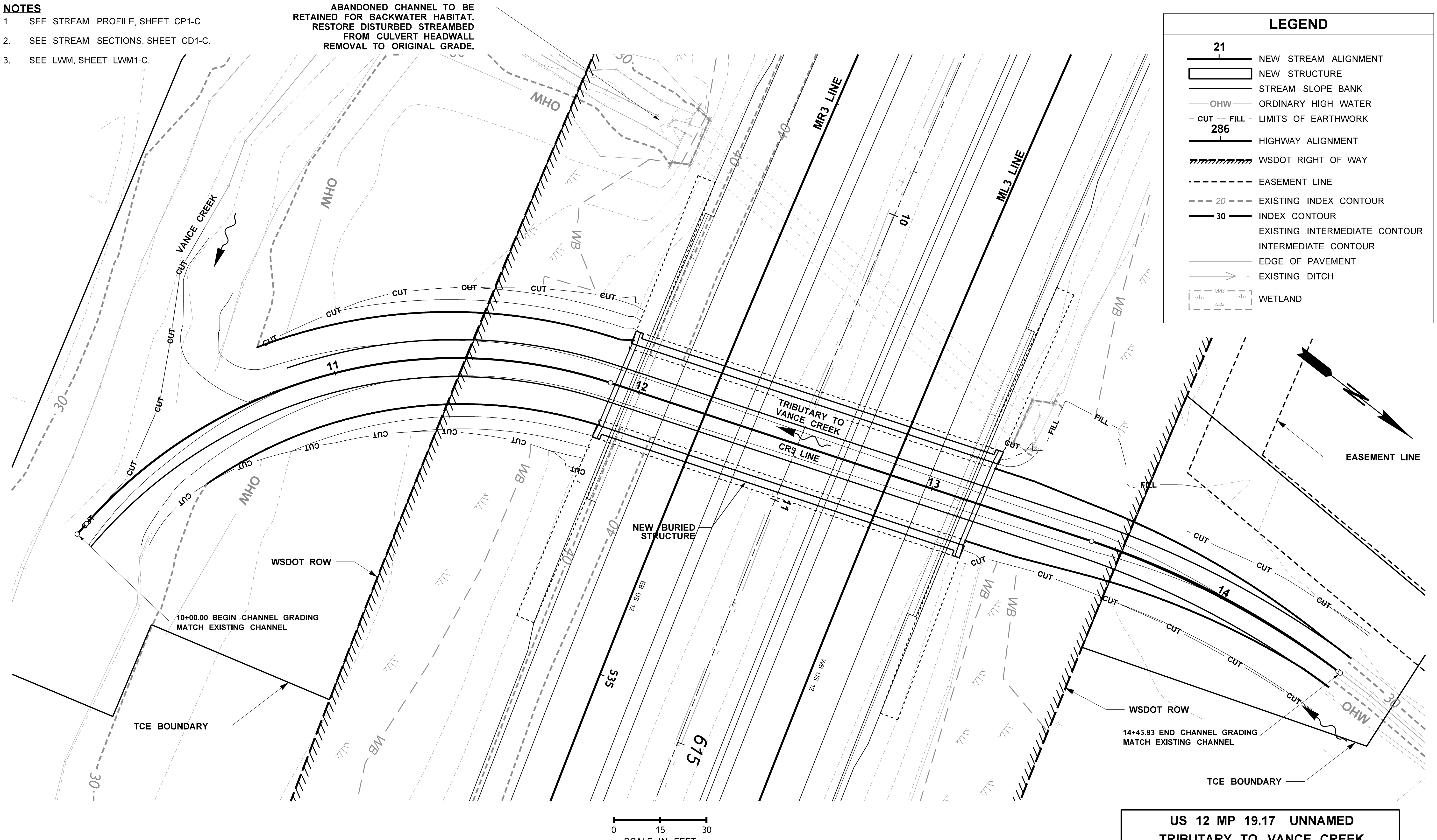
Dmax =	**4**
D[in]	
12.000	163.95
10.000	151.03
8.000	136.60
6.000	120.02
5.000	110.56
4.000	100.00
3.000	87.86
2.500	80.94
2.000	73.20
1.500	64.32
1.000	53.59
0.500	39.23
0.187	25.20
0.017	8.50
0.003	3.90

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix D: Stream Plan Sheets, Profile, Details

NOTES

1. SEE STREAM PROFILE, SHEET CP1-C.
2. SEE STREAM SECTIONS, SHEET CD1-C.
3. SEE LWM, SHEET LWM1-C.



pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_PS_CR_001.dgn

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_PS_CR_001.dgn
TIME	2:26:49 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	D. HENNINGS
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO CR1-C

SHEET OF SHEETS

NOTES

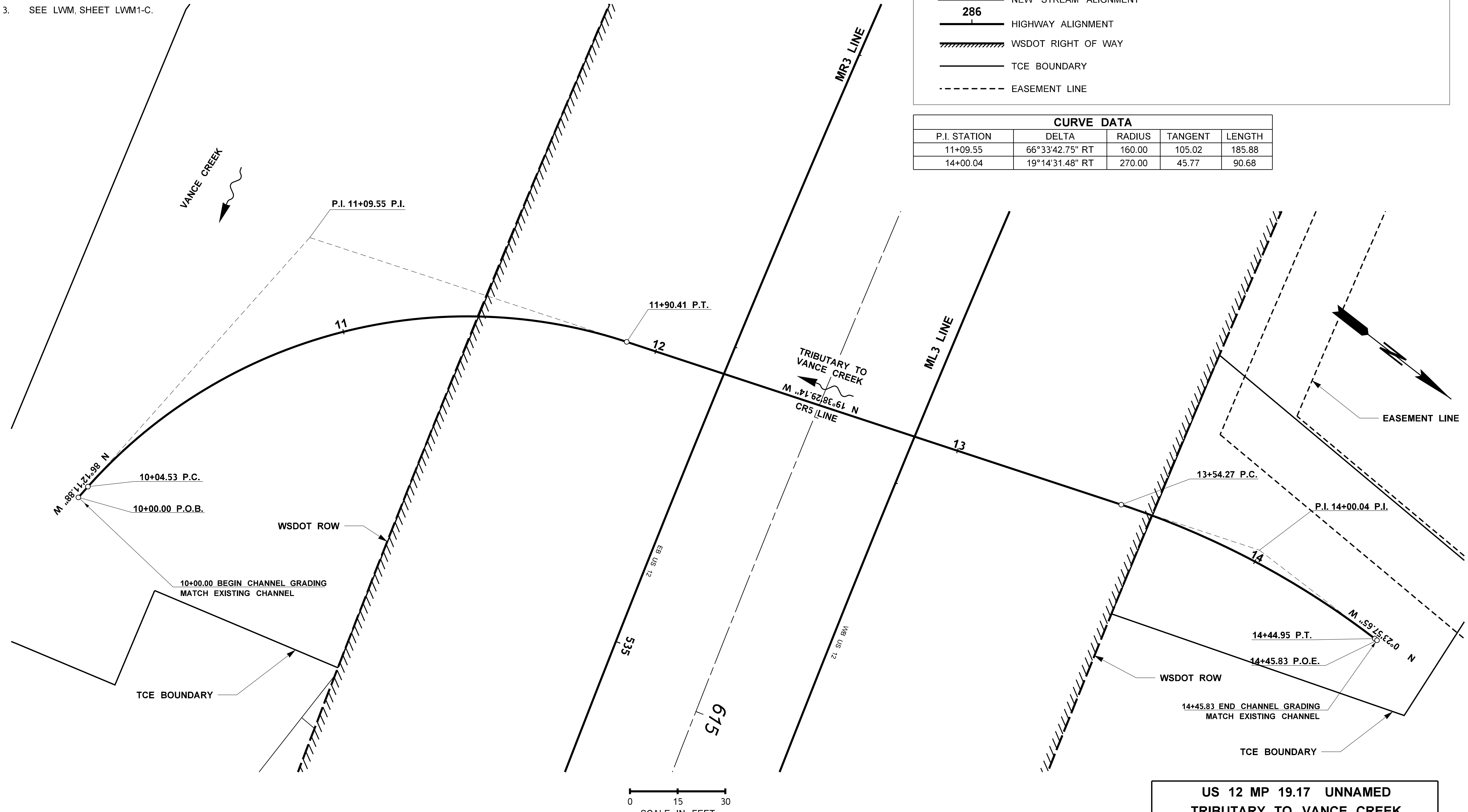
1. SEE STREAM PROFILE, SHEET CP1-C.
2. SEE STREAM SECTIONS, SHEET CD1-C.
3. SEE LWM, SHEET LWM1-C.

LEGEND

- 21 — NEW STREAM ALIGNMENT
- 286 — HIGHWAY ALIGNMENT
- WSDOT RIGHT OF WAY
- TCE BOUNDARY
- EASEMENT LINE

CURVE DATA

P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
11+09.55	66°33'42.75" RT	160.00	105.02	185.88
14+00.04	19°14'31.48" RT	270.00	45.77	90.68



US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_PS_CR_002.dgn			
TIME	2:26:51 PM			
DATE	10/24/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	D. HENNINGS			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO. XL6115

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

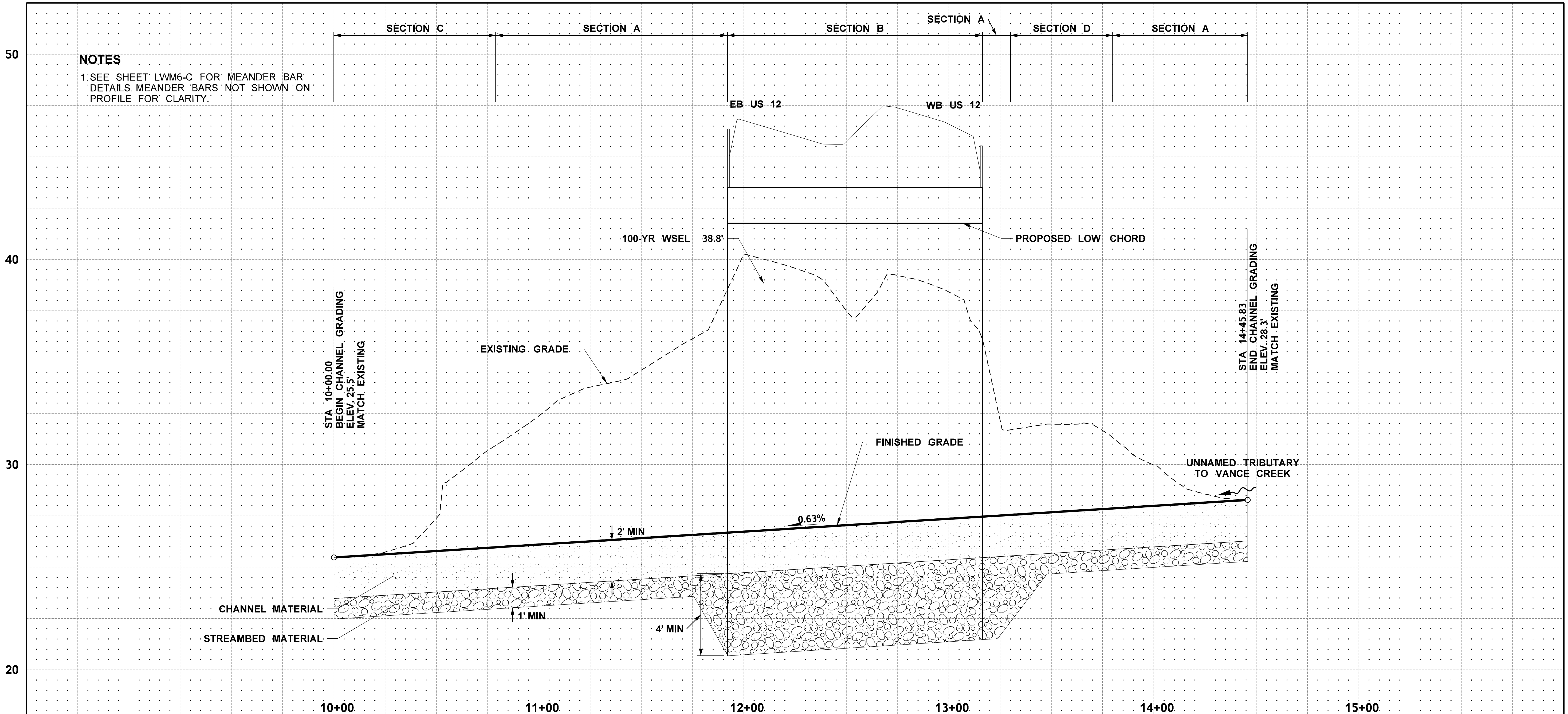
PLAN REF NO CR2-C

SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_PS_CR_002.dgn

NOTES

1. SEE SHEET LWM6-C FOR MEANDER BAR DETAILS. MEANDER BARS NOT SHOWN ON PROFILE FOR CLARITY.



CR5 LINE PROFILE

COMMON BORROW = 43 C.Y.

STREAMBED SEDIMENT = 908 TONS

STREAMBED COBBLES 4" = 552 TONS

CHANNEL EXCAVATION INCL. HAUL = 3,599 C.Y.

DATUM

(NAVD) 88

SCALE

HORIZONTAL: 1" = 50'

VERTICAL: 1" = 5'

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_PR_CR_001.dgn
TIME	2:26:53 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH

FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115

LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PROFILE

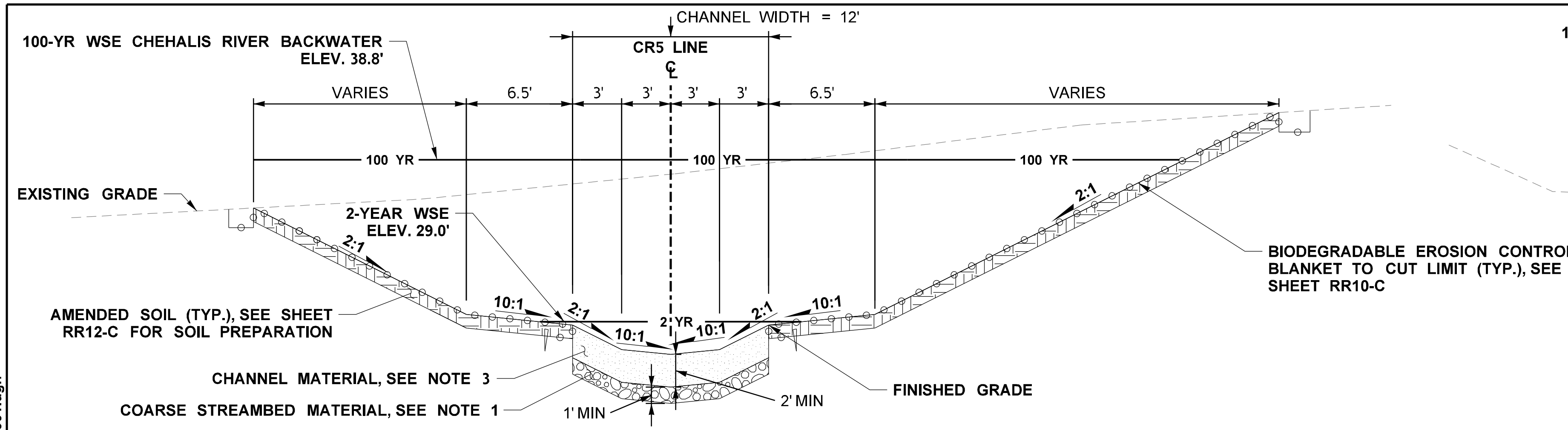
PLAN REF. NO. CP1-C

SHEET

OF

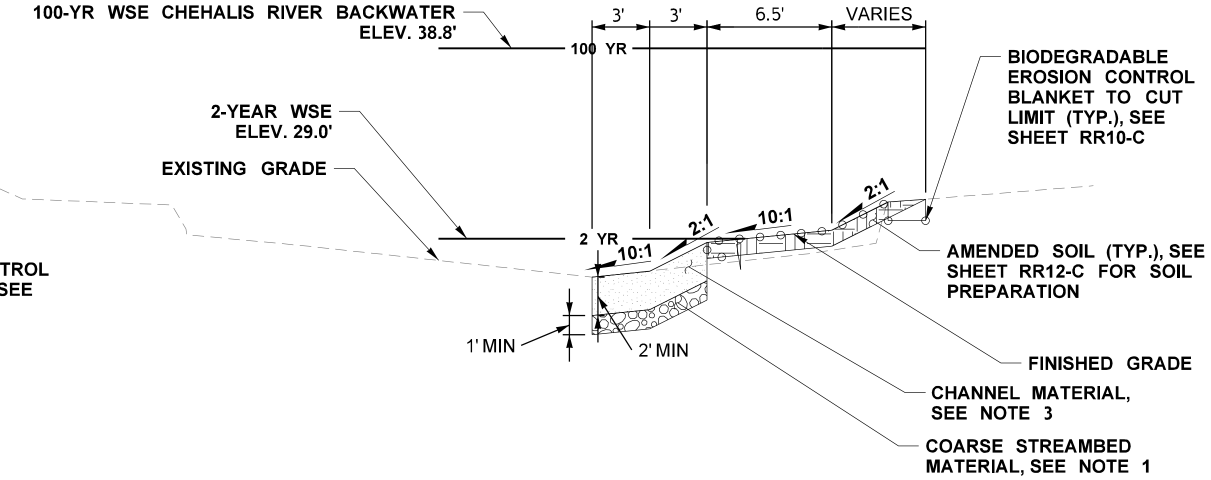
SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_PR_CR_001.dgn



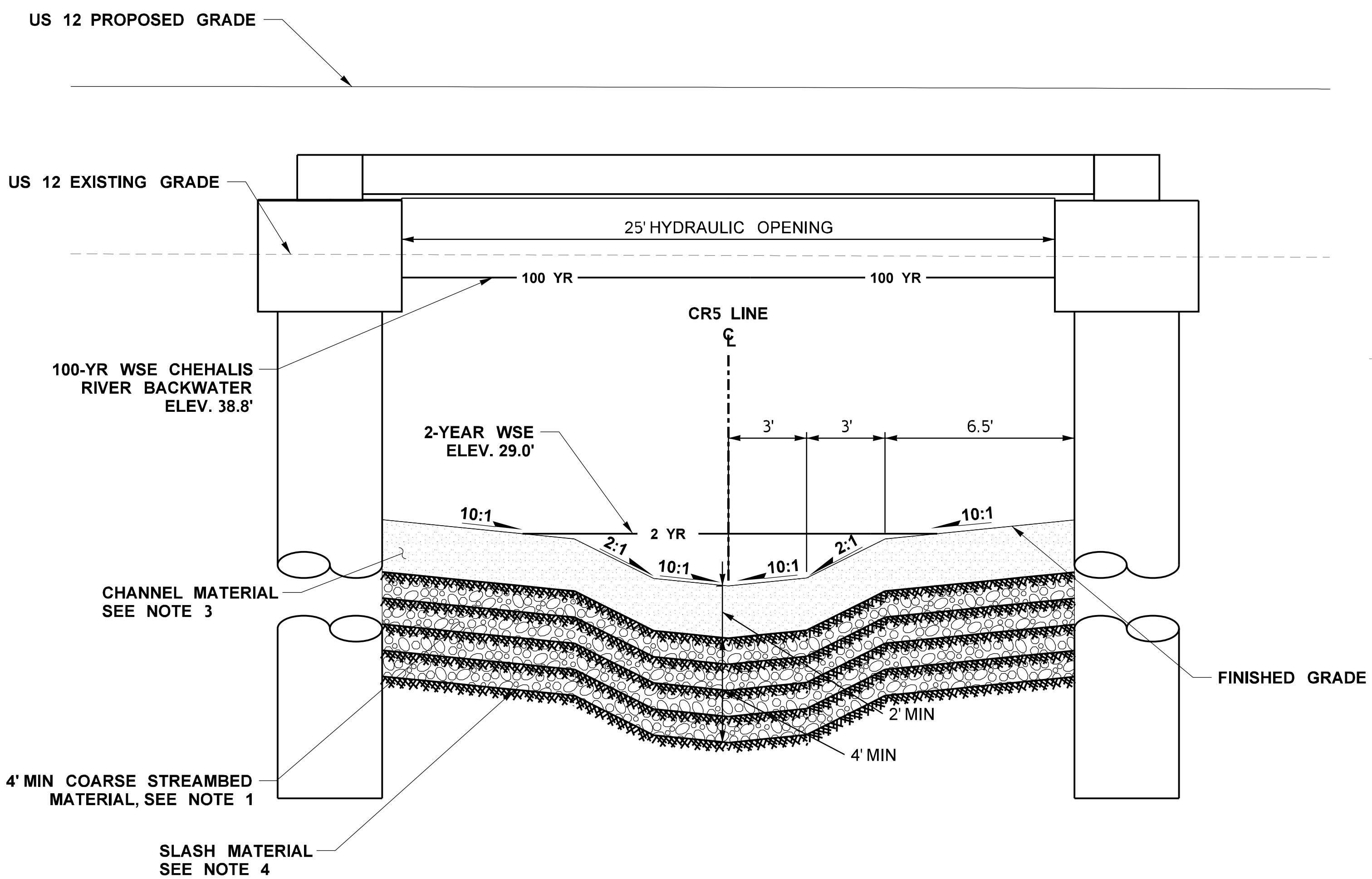
SECTION A - TYPICAL OPEN CHANNEL

CR5 10+79.00 TO CR5 11+91.98
CR5 13+16.38 TO CR5 13+30.00
CR5 13+80.00 TO CR5 14+45.83
NTS



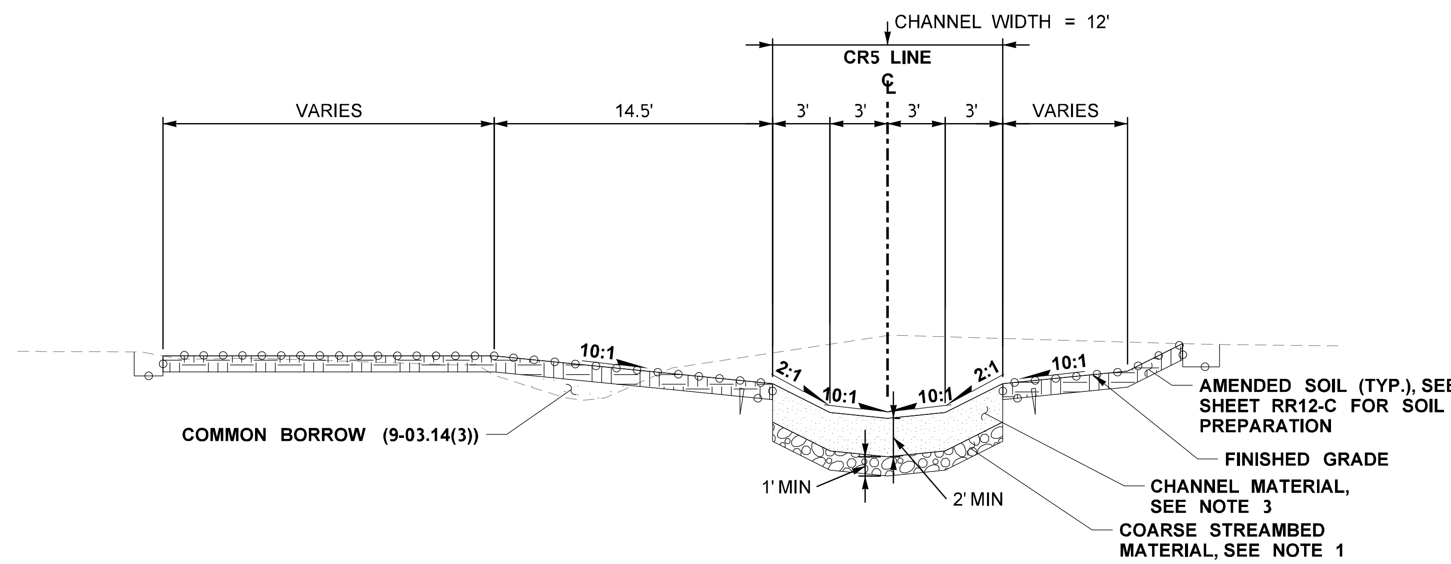
SECTION C - TRANSITION

CR5 10+00.00 TO CR5 10+79.00
NTS



SECTION B - TYPICAL SECANT PILE BURIED STRUCTURE

CR5 11+91.98 TO CR5 13+16.38
NTS



SECTION D - FILL EXISTING CHANNEL

CR5 13+30.00 TO CR5 13+80.00
NTS

NOTES

1. COARSE STREAMBED MATERIAL SHALL CONSIST OF 60 PERCENT 4" COBBLE (9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)). STREAMBED SEDIMENT SHALL BE INSTALLED IN 1' LIFTS WITH A LAYER OF SLASH BELOW AND ABOVE EACH LIFT.
2. A 3' MINIMUM FREEBOARD IS REQUIRED ABOVE THE 100-YEAR WSE FROM THE CHEHALIS RIVER BACKWATER.
3. CHANNEL MATERIAL SHALL CONSIST OF 100 PERCENT STREAMBED SEDIMENT (9.03.11(1)).
4. SLASH MATERIAL SHALL CONSIST OF SMALL LOGS OR BRANCHES THAT HAVE A MAXIMUM DIAMETER OF 4 INCHES AND A MAXIMUM LENGTH OF 6 FEET.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_CR_001.dgn		
TIME	2:26:58 PM		
DATE	10/24/2022		
PLOTTED BY	Rhw		
DESIGNED BY	K. COMINGS		
ENTERED BY	R. WILCOX		
CHECKED BY	J. GAGE		
PROJ. ENGR.	B. ELLIOTT		
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001
JOB NUMBER 21C522
CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

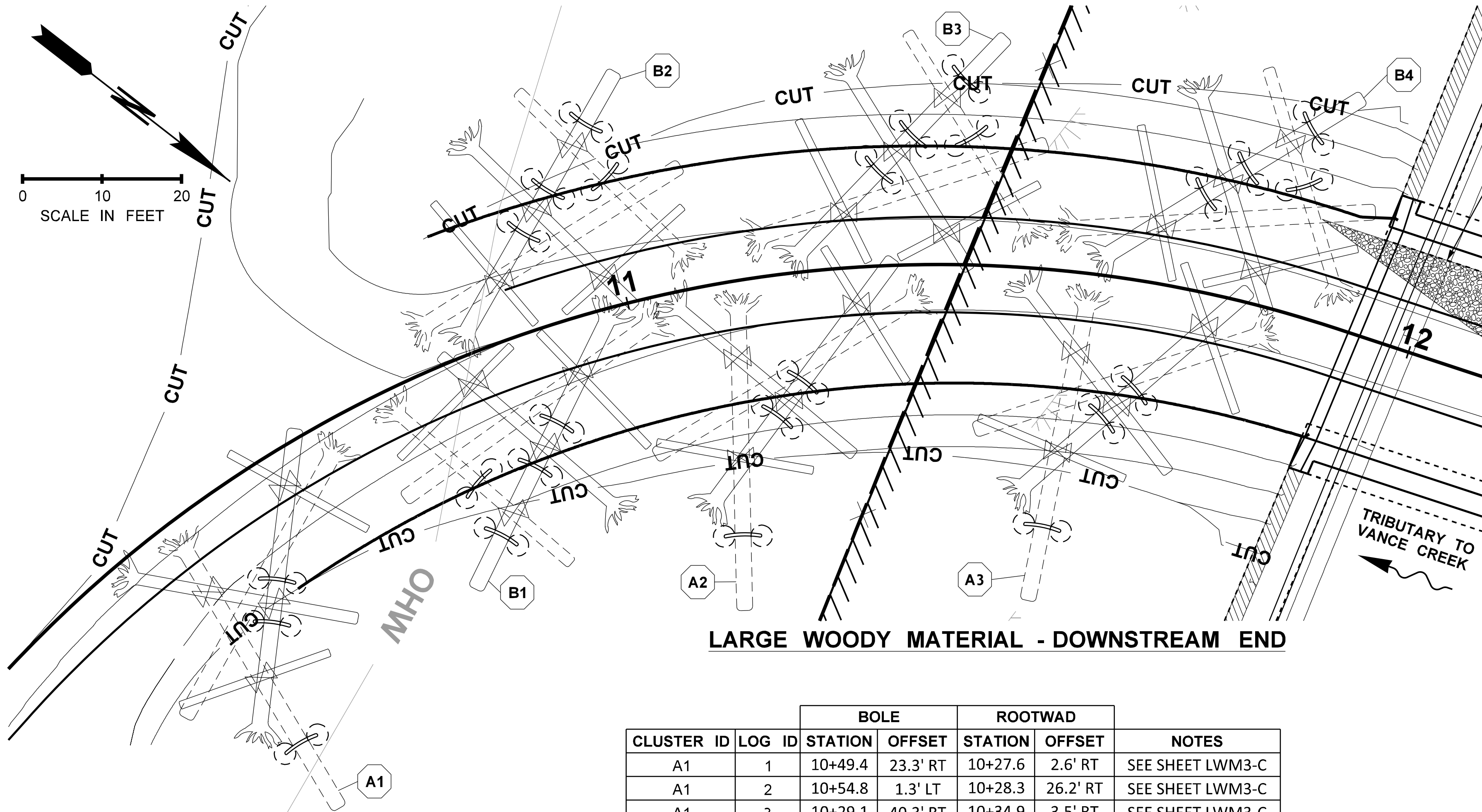
Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

PLAN REF NO CD1-C
SHEET
OF
SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_CR_001.dgn



LARGE WOODY MATERIAL - DOWNSTREAM END

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (17 TOTAL)

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (11 TOTAL)

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (14 TOTAL)

ROCK COLLAR - 3-MAN BOULDER (50 TOTAL BOULDERS), SEE SHEET LWM7-C

CABLE LASHING, SEE SHEET LWM6-C

CLUSTER ID, SEE SHEETS LWM3-C, LWM4-C, AND LWM5-C

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
A1	1	10+49.4	23.3' RT	10+27.6	2.6' RT	SEE SHEET LWM3-C
A1	2	10+54.8	1.3' LT	10+28.3	26.2' RT	SEE SHEET LWM3-C
A1	3	10+29.1	40.3' RT	10+34.9	3.5' RT	SEE SHEET LWM3-C
A1	4	10+20.5	19.9' RT	10+57.3	4.2' RT	SEE SHEET LWM3-C
A1	5	10+43.0	24.7' RT	10+20.9	17.8' RT	SEE SHEET LWM3-C
A1	6	10+57.3	14.5' RT	10+46.4	3.4' LT	SEE SHEET LWM3-C
B1	1	10+75.3	1.1' LT	10+90.5	23.9' RT	SEE SHEET LWM4-C
B1	2	10+66.6	27.3' RT	10+97.3	1.5' RT	SEE SHEET LWM4-C
B1	3	10+81.8	29.1' RT	10+67.8	3.4' RT	SEE SHEET LWM4-C
B1	4	10+63.3	13.1' RT	11+02.2	3.3' RT	SEE SHEET LWM4-C
B1	5	10+65.2	8.3' RT	10+84.5	0.9' RT	SEE SHEET LWM4-C
B1	6	10+98.0	18.1' RT	10+88.3	0.3' RT	SEE SHEET LWM4-C
B2	1	11+00.9	0.7' RT	10+87.7	24.4' LT	SEE SHEET LWM4-C
B2	2	11+04.7	28.9' LT	10+79.9	2.9' LT	SEE SHEET LWM4-C
B2	3	10+94.1	29.34' LT	11+07.9	4.9' LT	SEE SHEET LWM4-C
B2	4	11+09.8	15.4' LT	10+75.5	5.5' LT	SEE SHEET LWM4-C
B2	5	11+09.1	10.4' LT	10+91.9	1.1' LT	SEE SHEET LWM4-C
B2	6	10+81.6	19.5' LT	10+88.2	0.7' LT	SEE SHEET LWM4-C
A2	1	11+27.1	23.4' RT	11+06.2	2.1' RT	SEE SHEET LWM3-C
A2	2	11+33.8	0.9' LT	11+05.7	26.2' RT	SEE SHEET LWM3-C
A2	3	11+06.5	41.0' RT	11+13.7	3.4' RT	SEE SHEET LWM3-C
A2	4	10+98.5	19.4' RT	11+36.3	4.35' RT	SEE SHEET LWM3-C
A2	5	11+20.9	24.9' RT	10+99.2	17.9' RT	SEE SHEET LWM3-C
A2	6	11+35.2	14.8' RT	11+25.3	3.0' LT	SEE SHEET LWM3-C

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
B3	1	11+43.4	0.7' RT	11+29.7	24.2' LT	SEE SHEET LWM4-C
B3	2	11+46.7	28.9' LT	11+22.3	2.5' LT	SEE SHEET LWM4-C
B3	3	11+36.2	29.2' LT	11+50.4	5.3' LT	SEE SHEET LWM4-C
B3	4	11+51.9	16.0' LT	11+18.0	5.2' LT	SEE SHEET LWM4-C
B3	5	11+51.6	10.8' LT	11+34.7	1.1' LT	SEE SHEET LWM4-C
B3	6	11+23.8	19.4' LT	11+30.5	0.5' LT	SEE SHEET LWM4-C
A3	1	11+73.6	23.0' RT	11+51.2	2.8' RT	SEE SHEET LWM3-C
A3	2	11+78.8	1.9' LT	11+52.5	27.4' RT	SEE SHEET LWM3-C
A3	3	11+54.7	41.9' RT	11+58.8	4.0' RT	SEE SHEET LWM3-C
A3	4	11+44.7	20.9' RT	11+81.5	3.6' RT	SEE SHEET LWM3-C
A3	5	11+67.5	24.9' RT	11+45.2	19.2' RT	SEE SHEET LWM3-C
A3	6	11+81.0	13.8' RT	11+70.0	3.0' LT	SEE SHEET LWM3-C
B4	1	11+81.7	0.8' RT	11+68.4	24.4' LT	SEE SHEET LWM4-C
B4	2	11+85.6	28.8' LT	11+60.6	2.7' LT	SEE SHEET LWM4-C
B4	3	11+74.9	29.3' LT	11+88.8	4.9' LT	SEE SHEET LWM4-C
B4	4	11+90.6	15.4' LT	11+56.2	5.5' LT	SEE SHEET LWM4-C
B4	5	11+90.0	10.3' LT	11+72.8	1.2' LT	SEE SHEET LWM4-C
B4	6	11+62.3	19.4' LT	11+68.9	0.7' LT	SEE SHEET LWM4-C

LEGEND

21 NEW STREAM ALIGNMENT

NEW STRUCTURE

STREAM SLOPE BANK

OHW ORDINARY HIGH WATER

CUT – FILL LIMITS OF EARTHWORK

286 HIGHWAY ALIGNMENT

WSDOT RIGHT OF WAY

EASEMENT LINE

20 EXISTING INDEX CONTOUR

30 INDEX CONTOUR

EXISTING INTERMEDIATE CONTOUR

INTERMEDIATE CONTOUR

EDGE OF PAVEMENT

EXISTING DITCH

WB WETLAND

BOLE END

ROOTWAD END

NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-C, LWM4-C, AND LWM5-C FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 38.8'

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_PS_LWM_001.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_PS_LWM_001.dgn			
TIME	2:27:06 PM			
DATE	10/24/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 STATE WASH

FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115

LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

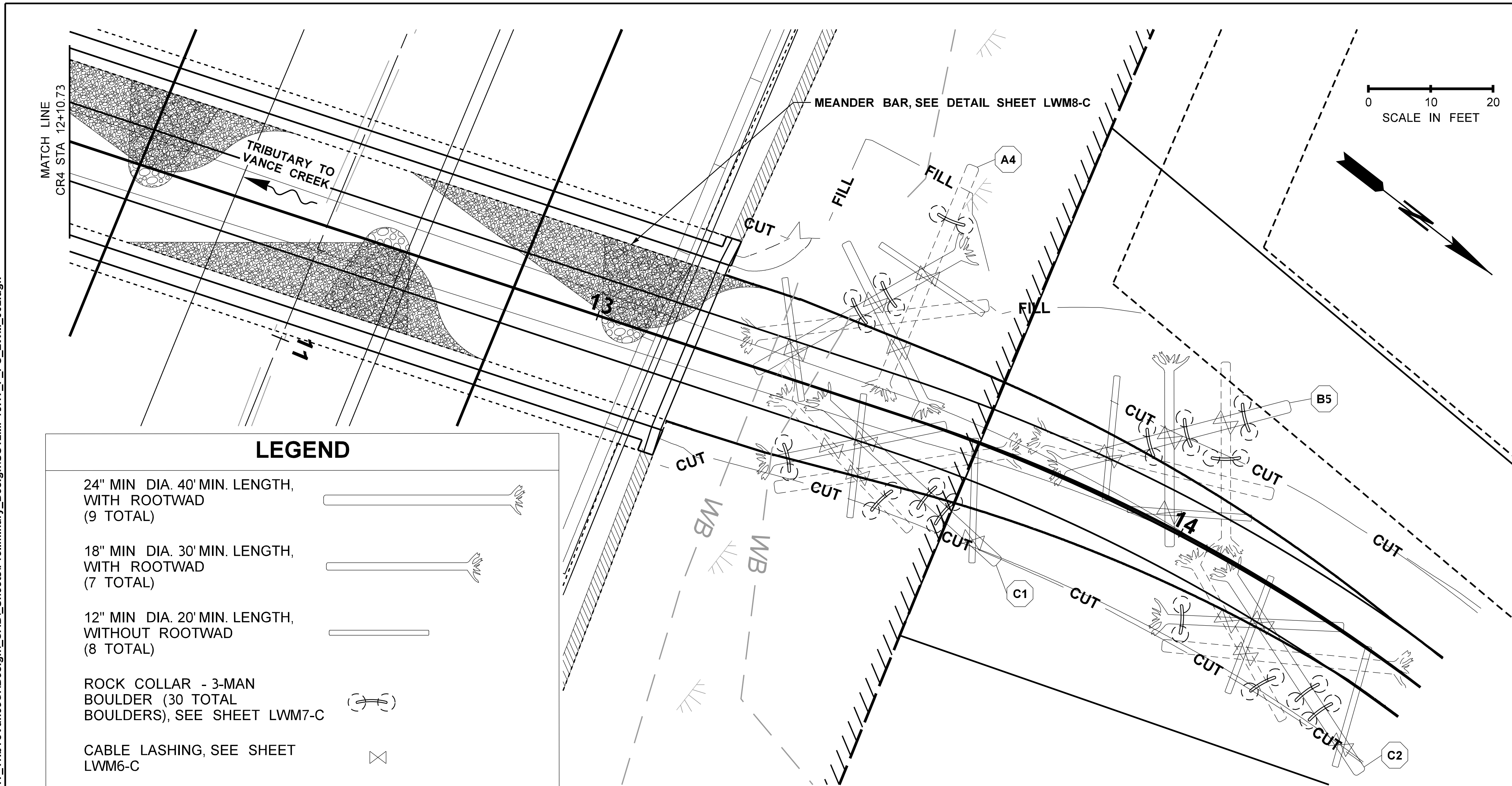
DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

PLAN REF NO LWM1-C

SHEET OF SHEETS



LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (9 TOTAL)

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (7 TOTAL)

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (8 TOTAL)

ROCK COLLAR - 3-MAN BOULDER (30 TOTAL BOULDERS), SEE SHEET LWM7-C

CABLE LASHING, SEE SHEET LWM6-C

CLUSTER ID, SEE SHEETS LWM3-C, LWM4-C, AND LWM5-C

LEGEND

21 — NEW STREAM ALIGNMENT

NEW STRUCTURE

STREAM SLOPE BANK

OHW — ORDINARY HIGH WATER

CUT FILL — LIMITS OF EARTHWORK

286 — HIGHWAY ALIGNMENT

WSDOT RIGHT OF WAY

EASEMENT LINE

20 — EXISTING INDEX CONTOUR

30 — INDEX CONTOUR

EXISTING INTERMEDIATE CONTOUR

INTERMEDIATE CONTOUR

EDGE OF PAVEMENT

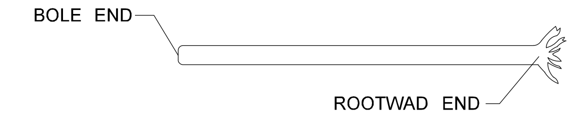
EXISTING DITCH

WB — WETLAND

LARGE WOODY MATERIAL - UPSTREAM END

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
A4	1	13+34.1	23.6' LT	13+54.1	3.1' LT	SEE SHEET LWM3-C
A4	2	13+26.8	0.6' RT	13+52.3	27.7' LT	SEE SHEET LWM3-C
A4	3	13+49.7	41.6' LT	13+46.6	3.6' LT	SEE SHEET LWM3-C
A4	4	13+58.7	21.1' LT	13+25.0	5.1' LT	SEE SHEET LWM3-C
A4	5	13+39.2	25.0' LT	13+58.6	19.4' LT	SEE SHEET LWM3-C
A4	6	13+26.5	15.1' LT	13+35.4	2.8' RT	SEE SHEET LWM3-C
C1	1	13+74.9	16.8' RT	13+38.9	2.0' RT	SEE SHEET LWM5-C
C1	2	13+58.6	0.9' LT	13+33.8	13.5' RT	SEE SHEET LWM5-C
C1	3	13+58.8	17.1' RT	13+33.2	3.5' RT	SEE SHEET LWM5-C
C1	4	13+35.6	17.4' RT	13+69.4	0.2' LT	SEE SHEET LWM5-C
C1	5	13+48.6	18.1' RT	13+44.4	1.4' LT	SEE SHEET LWM5-C
C1	6	13+70.6	18.5' RT	13+63.7	0.4' LT	SEE SHEET LWM5-C

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
B5	1	14+00.0	2.8' RT	13+87.0	22.8' LT	SEE SHEET LWM4-C
B5	2	14+05.5	26.3' LT	13+78.3	1.6' LT	SEE SHEET LWM4-C
B5	3	13+94.2	27.8' LT	14+07.1	2.2' LT	SEE SHEET LWM4-C
B5	4	14+09.8	12.7' LT	13+74.3	4.5' LT	SEE SHEET LWM4-C
B5	5	14+08.7	7.7' LT	13+90.6	0.4' RT	SEE SHEET LWM4-C
B5	6	13+80.4	18.3' LT	13+86.8	0.7' RT	SEE SHEET LWM4-C
C2	1	14+45.7	16.4' RT	14+10.3	2.0' RT	SEE SHEET LWM5-C
C2	2	14+30.2	0.6' LT	14+04.7	13.2' RT	SEE SHEET LWM5-C
C2	3	14+30.7	17.1' RT	14+04.4	3.0' RT	SEE SHEET LWM5-C
C2	4	14+06.2	17.2' RT	14+40.9	0.2' LT	SEE SHEET LWM5-C
C2	5	14+20.0	18.6' RT	14+16.1	1.2' LT	SEE SHEET LWM5-C
C2	6	14+42.6	18.4' RT	14+35.4	0.4' LT	SEE SHEET LWM5-C



NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-C, LWM4-C, AND LWM5-C FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 38.8'

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_PS_LWM_002.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_PS_LWM_002.dgn
TIME	2:27:15 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

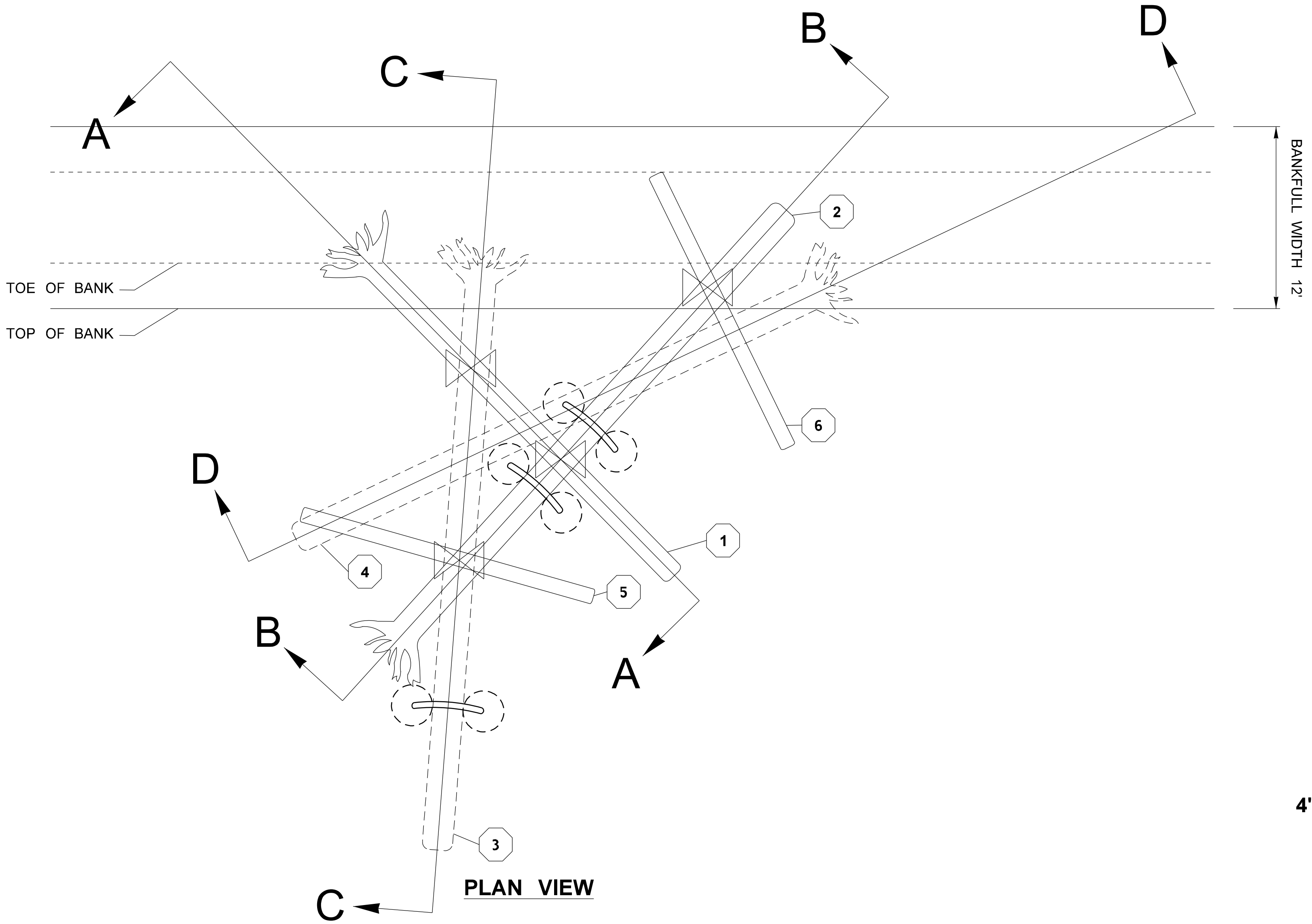
US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

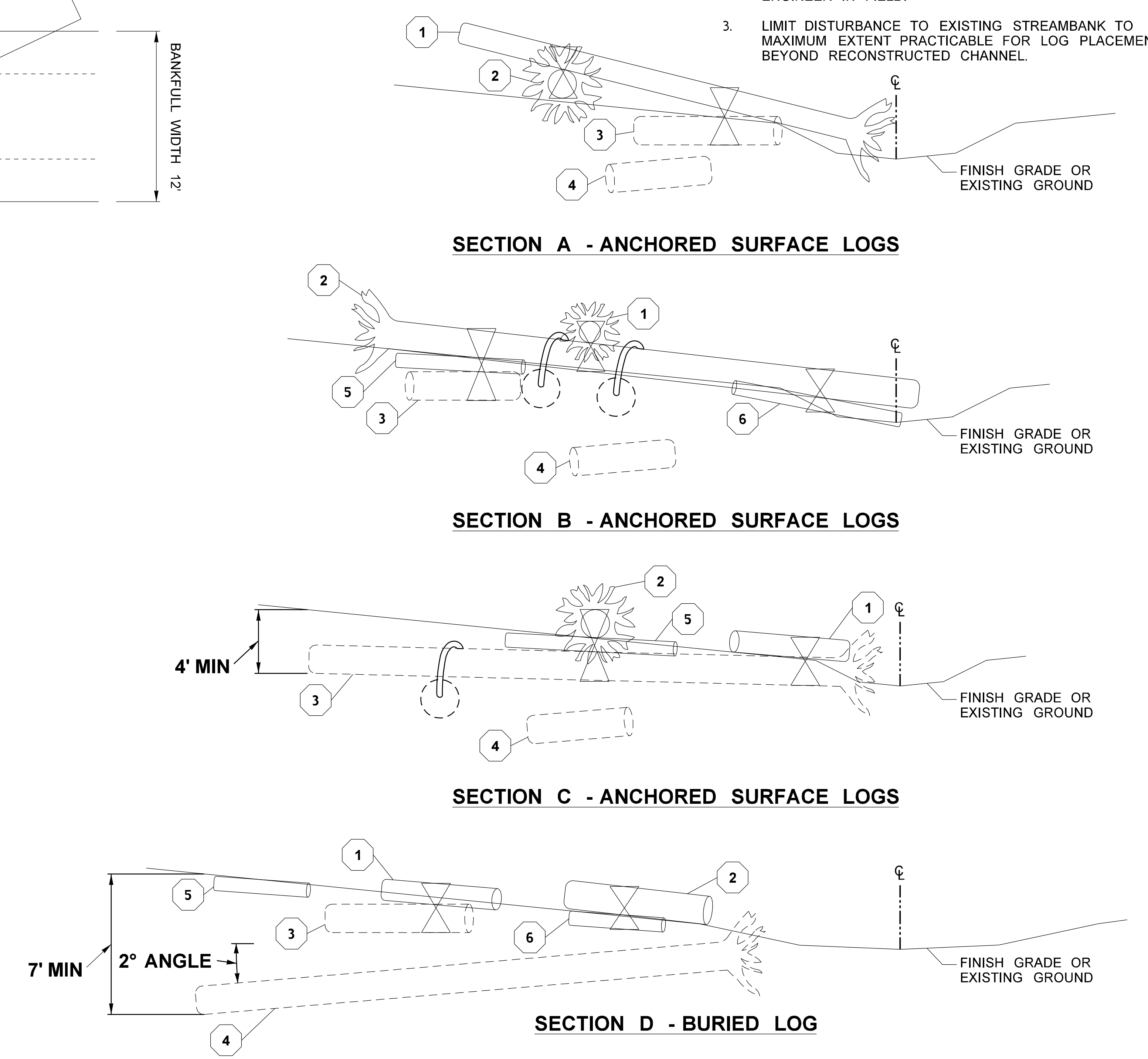
PLAN REF NO LWM2-C

SHEET OF SHEETS

NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



PLAN VIEW



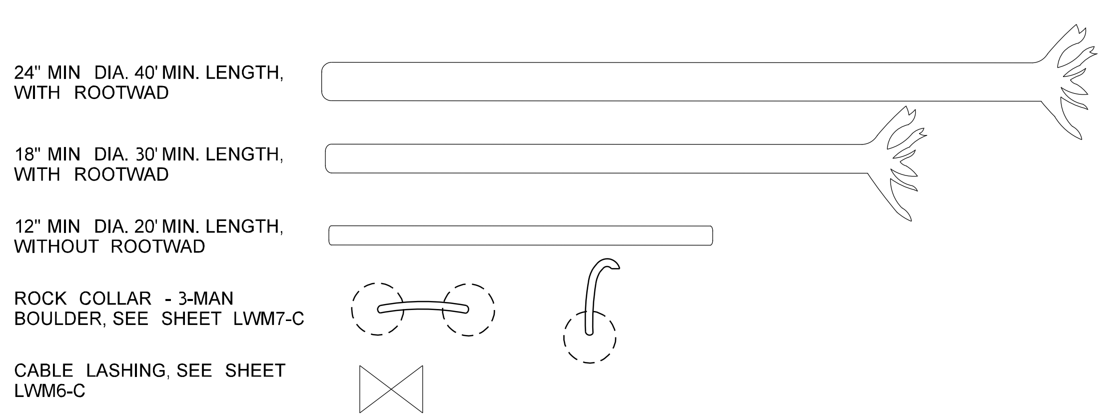
SECTION A - ANCHORED SURFACE LOGS

SECTION B - ANCHORED SURFACE LOGS

SECTION C - ANCHORED SURFACE LOGS

SECTION D - BURIED LOG

LEGEND



LARGE WOOD CLUSTER TYPE A

NTS

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_001.dgn
TIME	2:27:18 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115

LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

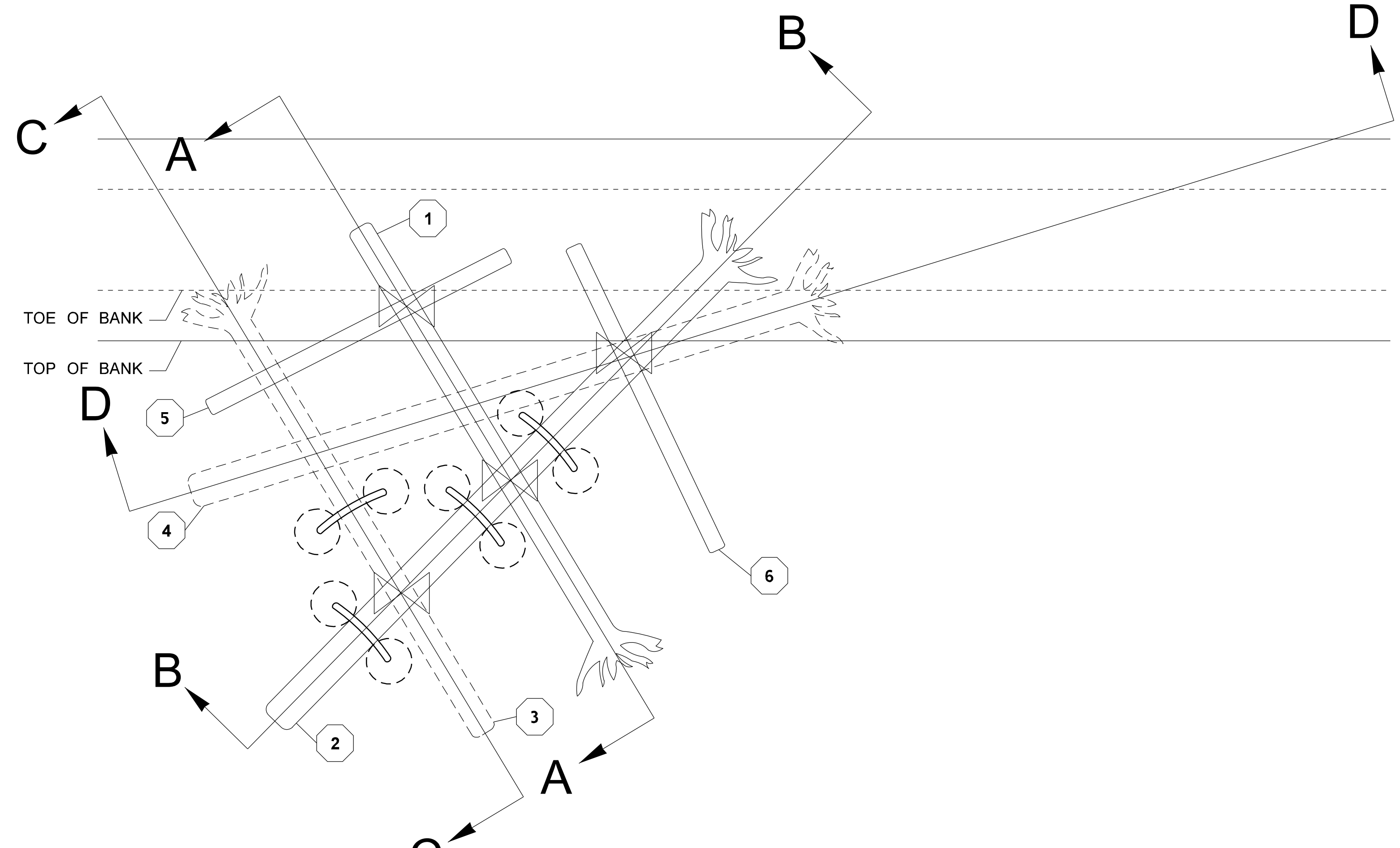
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM3-C

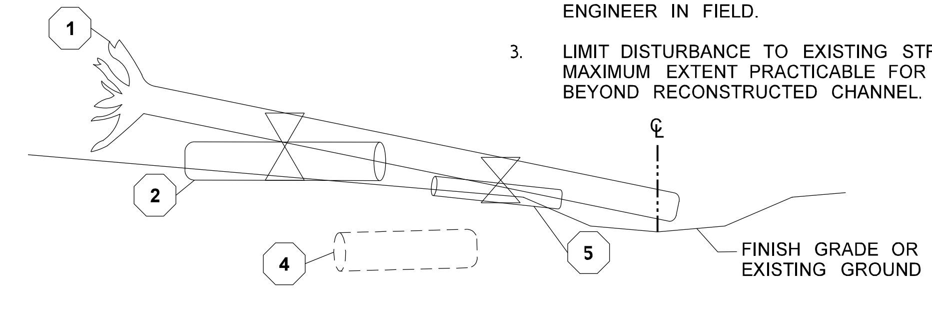
SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_001.dgn

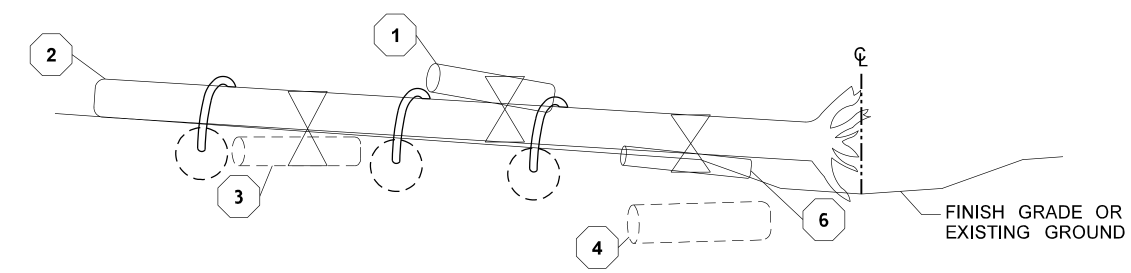
NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



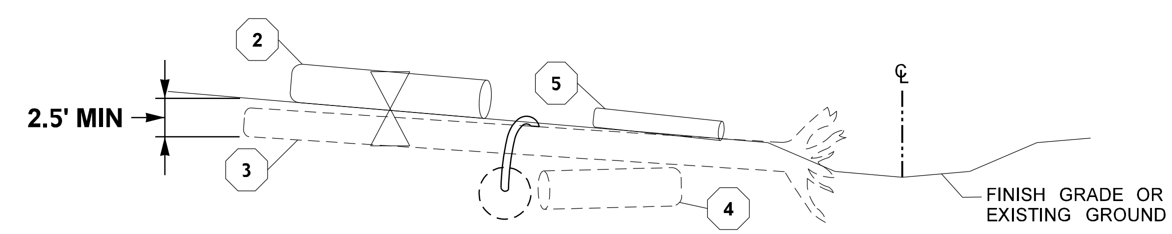
PLAN VIEW



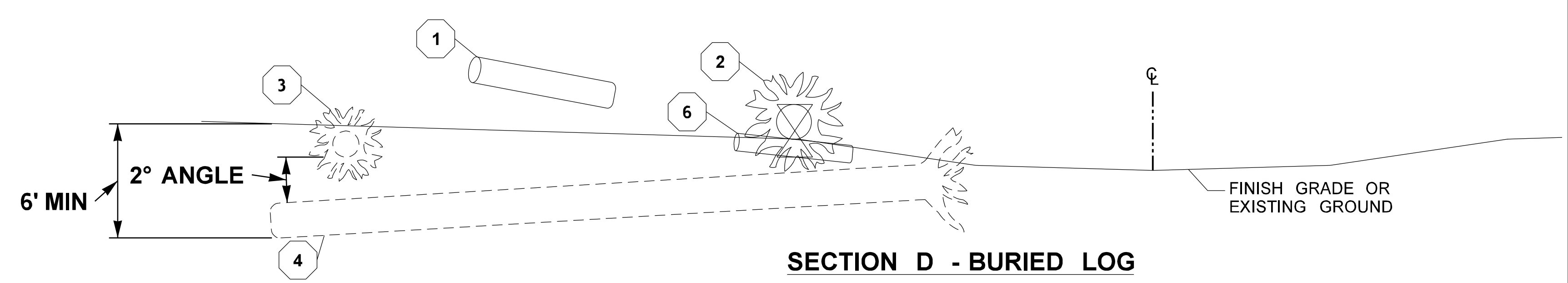
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS



SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

ROCK COLLAR - 3-MAN BOULDER, SEE SHEET LWM7-C

CABLE LASHING, SEE SHEET LWM6-C

LARGE WOOD CLUSTER TYPE B

NTS

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_002.dgn		
TIME	2:27:20 PM		
DATE	10/24/2022		
PLOTTED BY	Rhw		
DESIGNED BY	K. COMINGS		
ENTERED BY	R. WILCOX		
CHECKED BY	J. GAGE		
PROJ. ENGR.	B. ELLIOTT		
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

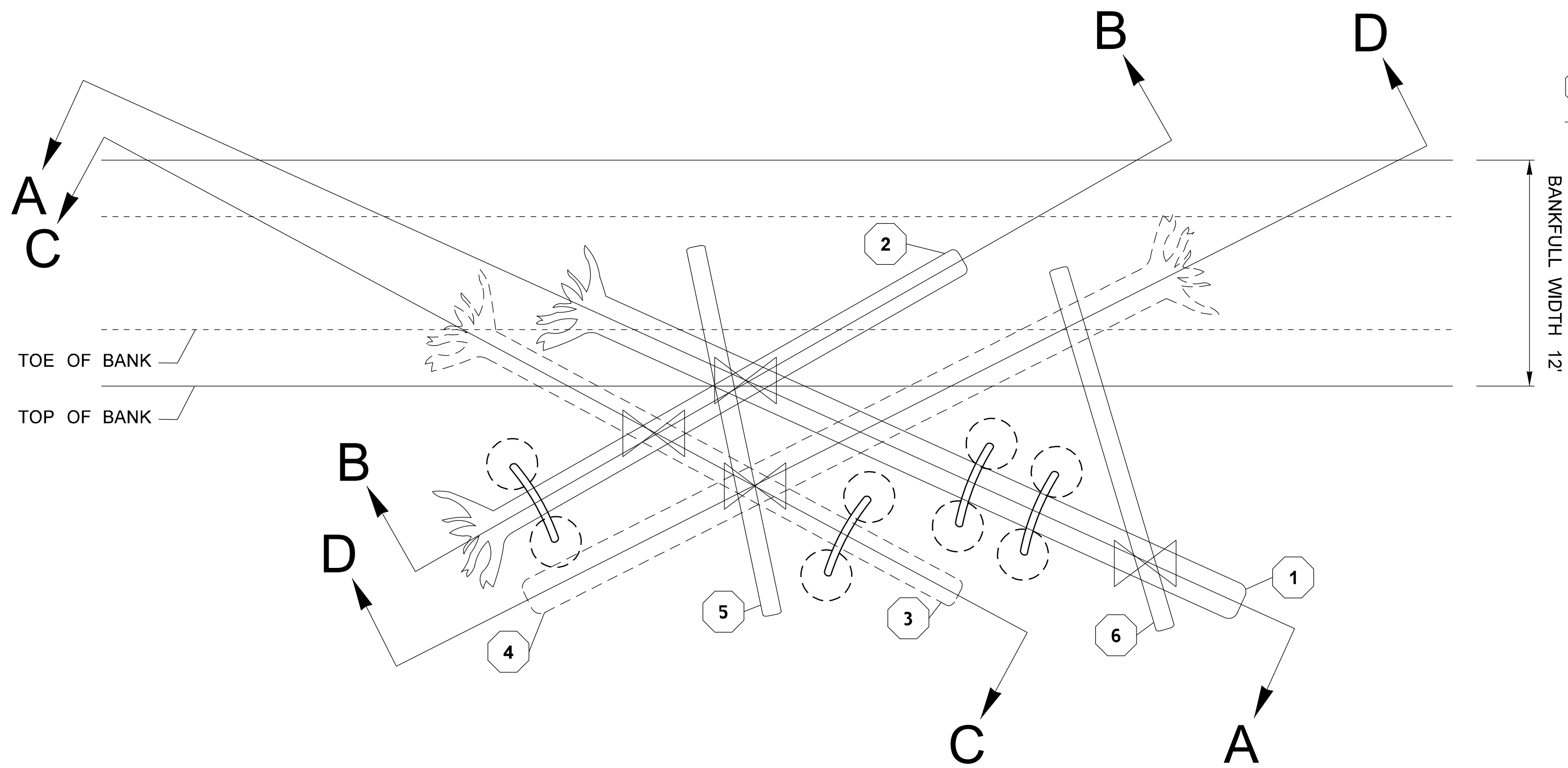
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM4-C

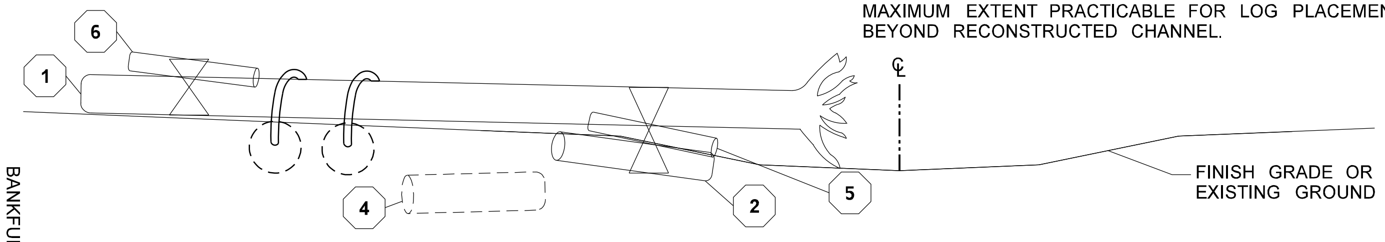
SHEET OF SHEETS

pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_002.dgn

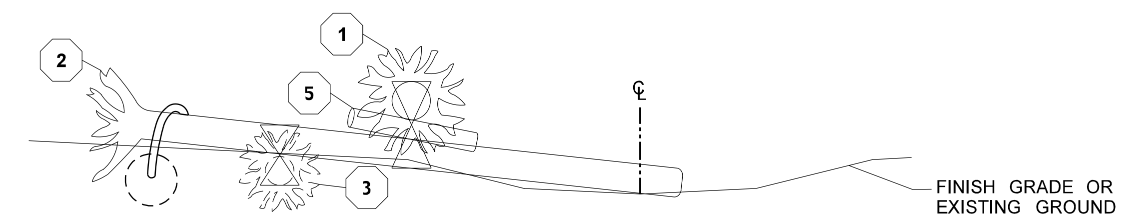
NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



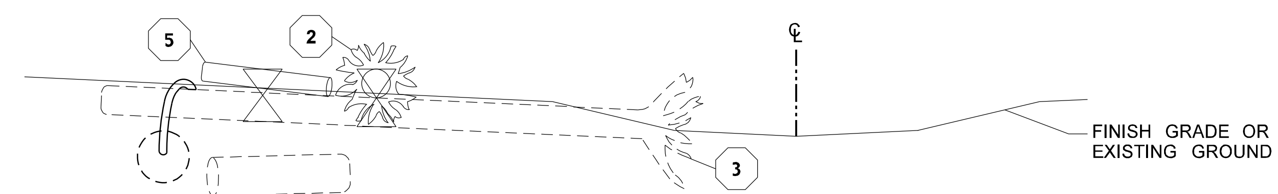
PLAN VIEW



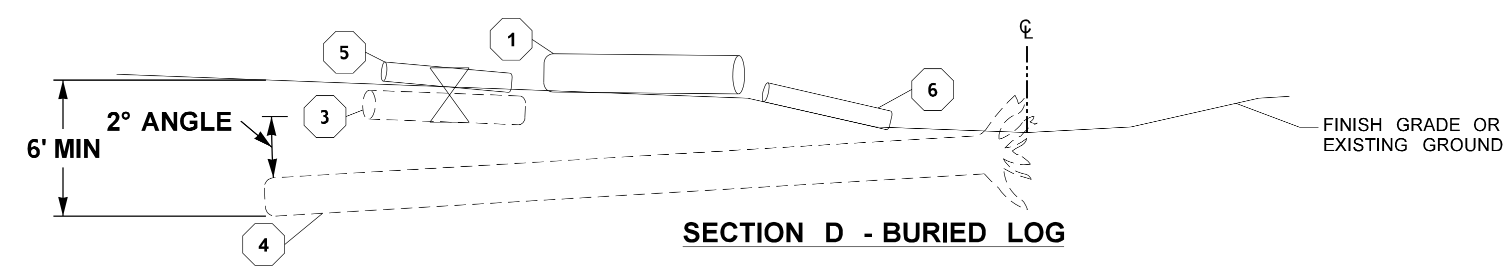
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS



SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

LEGEND

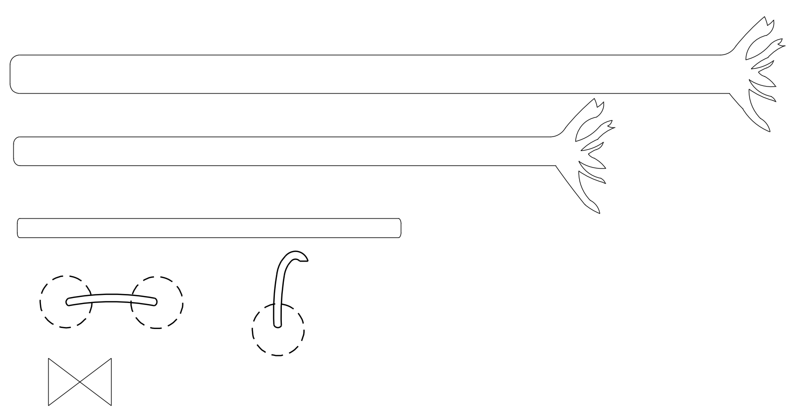
24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

ROCK COLLAR - 3-MAN BOULDER, SEE SHEET LWM7-C

CABLE LASHING, SEE SHEET LWM6-C



LARGE WOOD CLUSTER TYPE C

NTS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_003.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_003.dgn
TIME	2:27:23 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

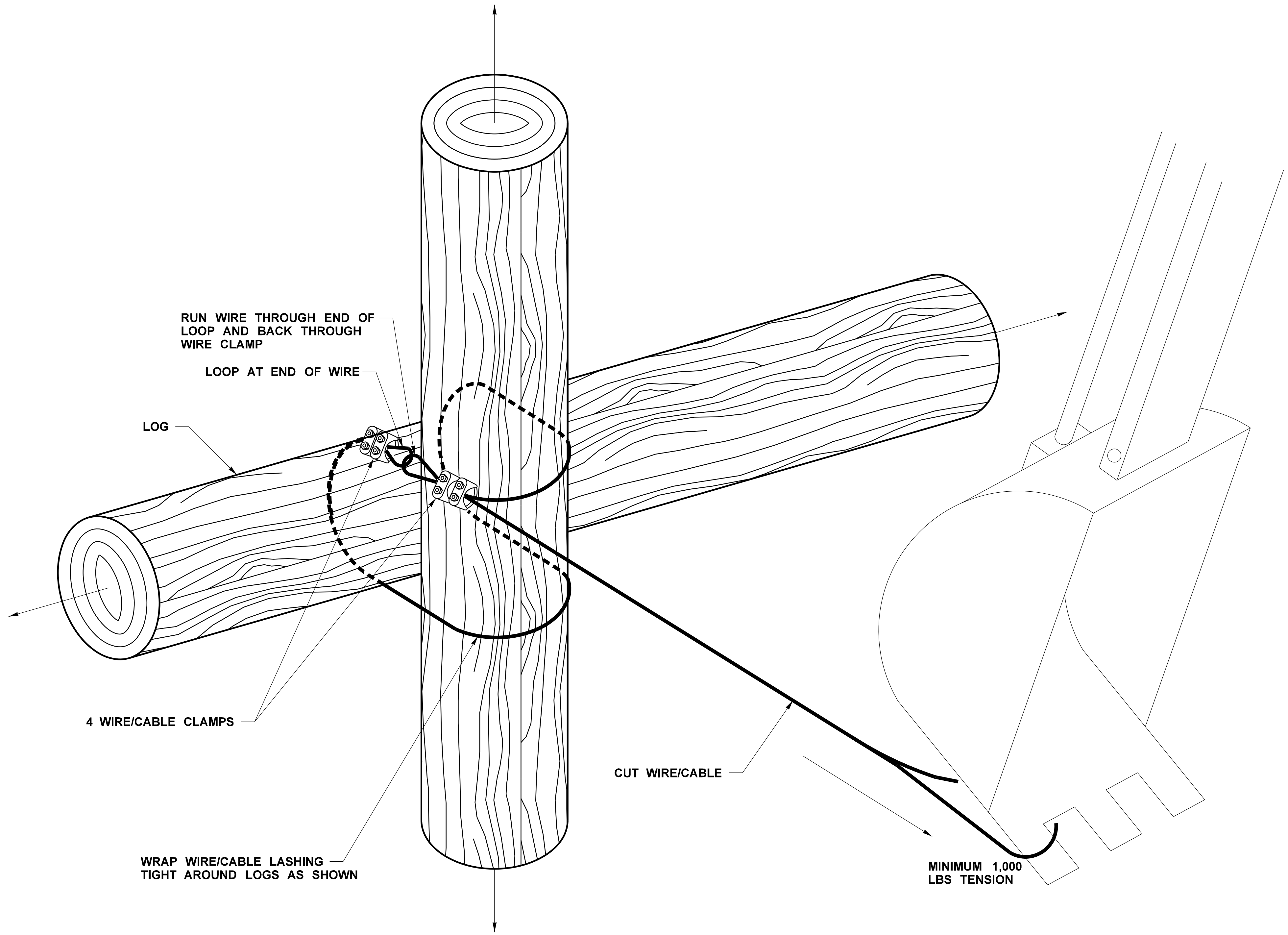
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM5-C

SHEET

OF

SHEETS



WIRE-ROPE LASHING CONNECTION

NTS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_004.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_004.dgn
TIME	2:27:25 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

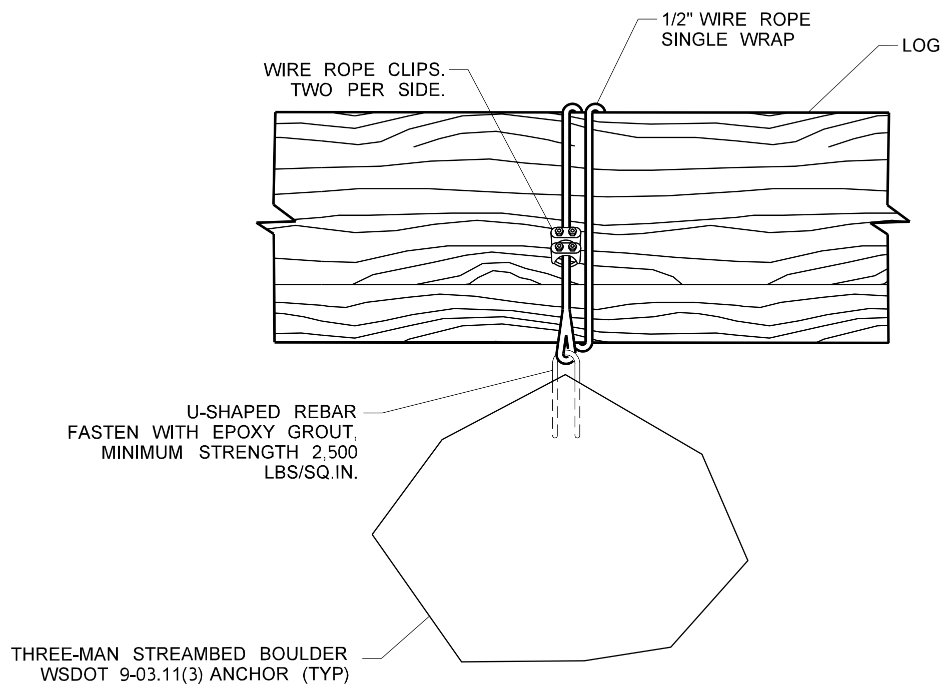
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM6-C

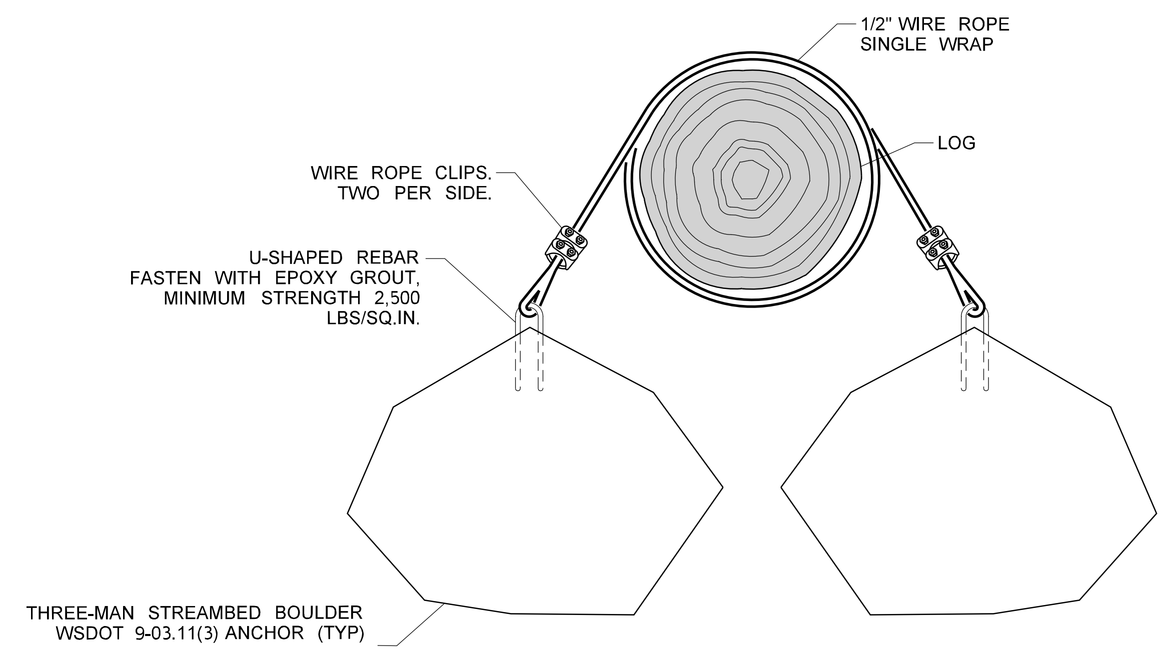
SHEET OF SHEETS

NOTES:

1. ROCK SHALL BE SUFFICIENTLY HARD TO NOT BREAK WHEN UNLOADED FROM THE HAUL VEHICLE AND/OR DROPPED FROM UP TO 8 FT AT THE STAGING AREA. ROCK BROKEN DURING TESTING SHALL BE REJECTED.
2. HOLES DRILLED IN ROCKS MUST BE THOROUGHLY CLEANED OF ALL ROCK POWDER, DIRT, AND DEBRIS PRIOR TO PLACEMENT OF EPOXY.
3. THE WIRE ROPE SHALL BE NON-OILED AND NON-GALVANIZED.
4. BOULDERS SHALL BE FULLY BURIED.



SIDE VIEW



SECTION VIEW

TYPICAL DETAIL ROCK COLLAR

NTS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_005.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_005.dgn
TIME	2:27:27 PM
DATE	10/24/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM7-C

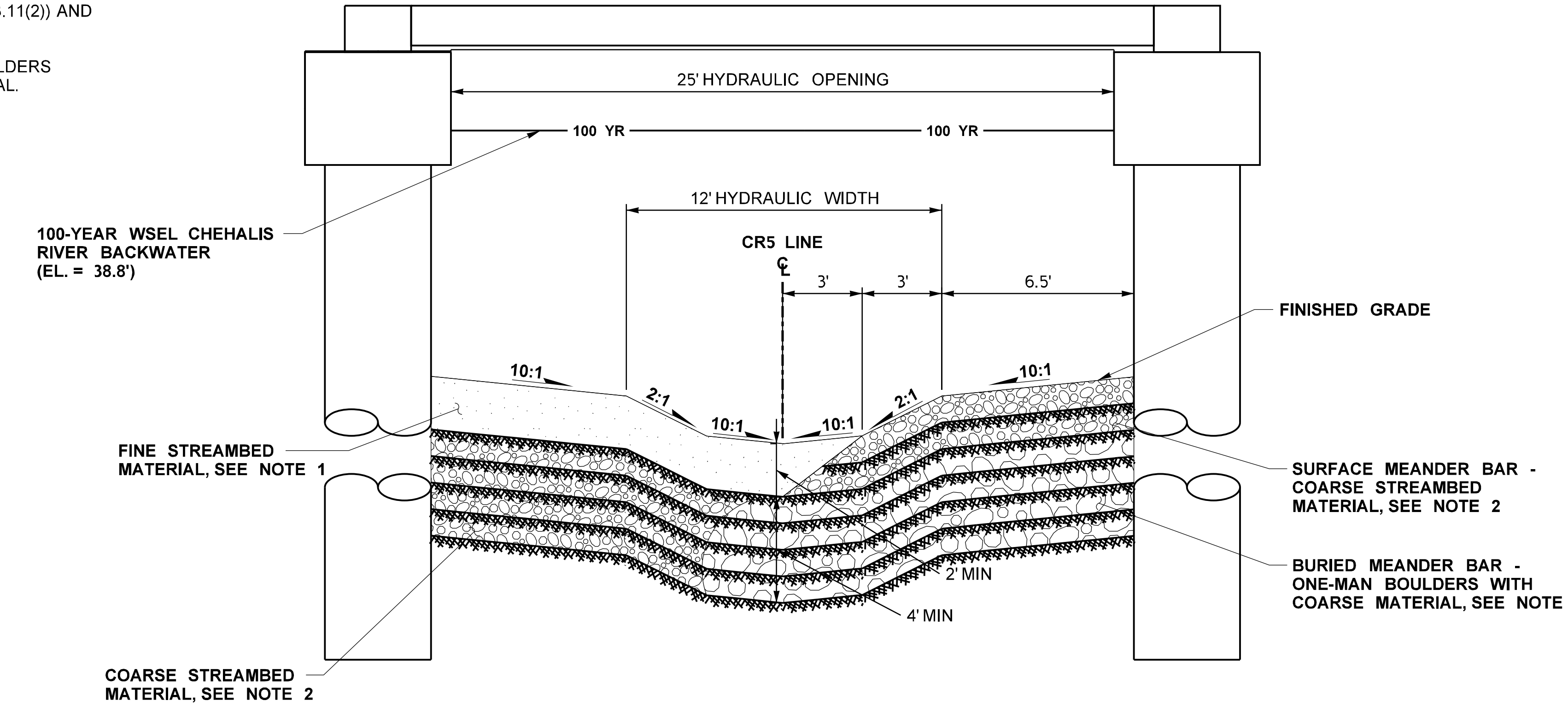
SHEET

OF

SHEETS

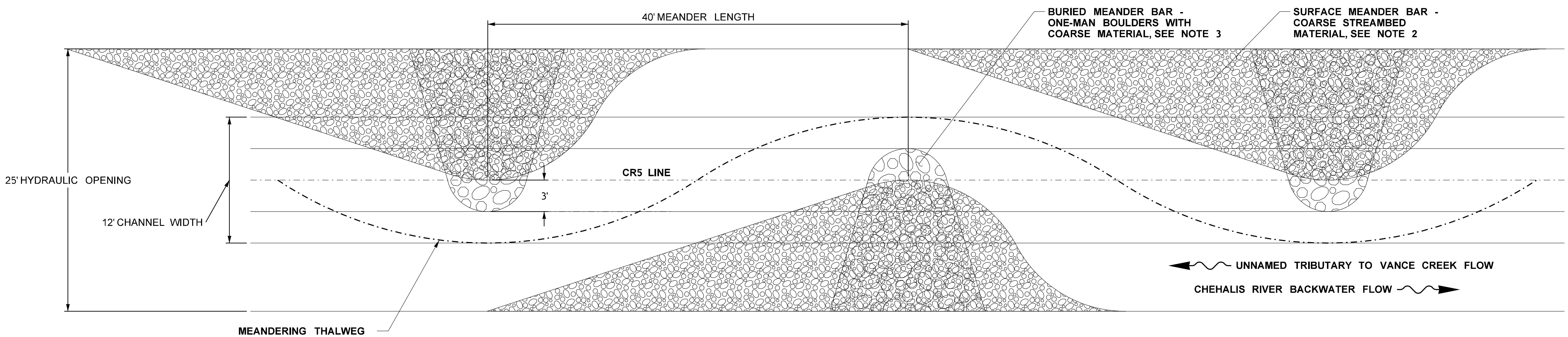
NOTES

1. FINE STREAMBED MATERIAL SHALL CONSIST OF EXISTING MATERIAL RESERVED FROM CHANNEL EXCAVATION.
2. COARSE STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 60 PERCENT 4" STREAMBED COBBLES (WSDOT 9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
3. BURIED MEANDER BAR SHALL CONSIST OF ONE-MAN BOULDERS (9-03.11(3)) BACKFILLED WITH COARSE STREAMBED MATERIAL.



MEANDER BAR

NTS



pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_006.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_006.dgn			
TIME	2:27:29 PM			
DATE	10/24/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

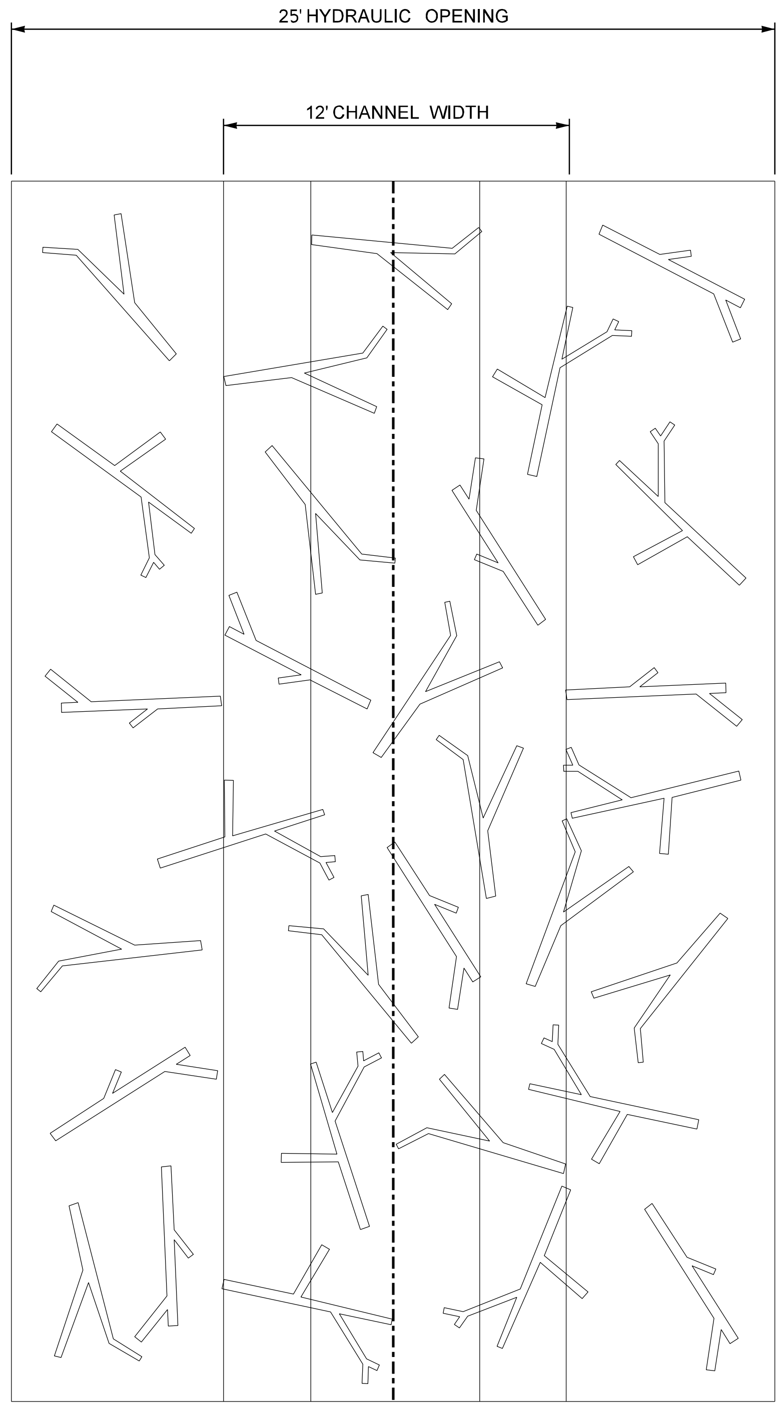
MEANDER BAR DETAILS

PLAN REF NO LWM8-C

SHEET

OF

SHEETS

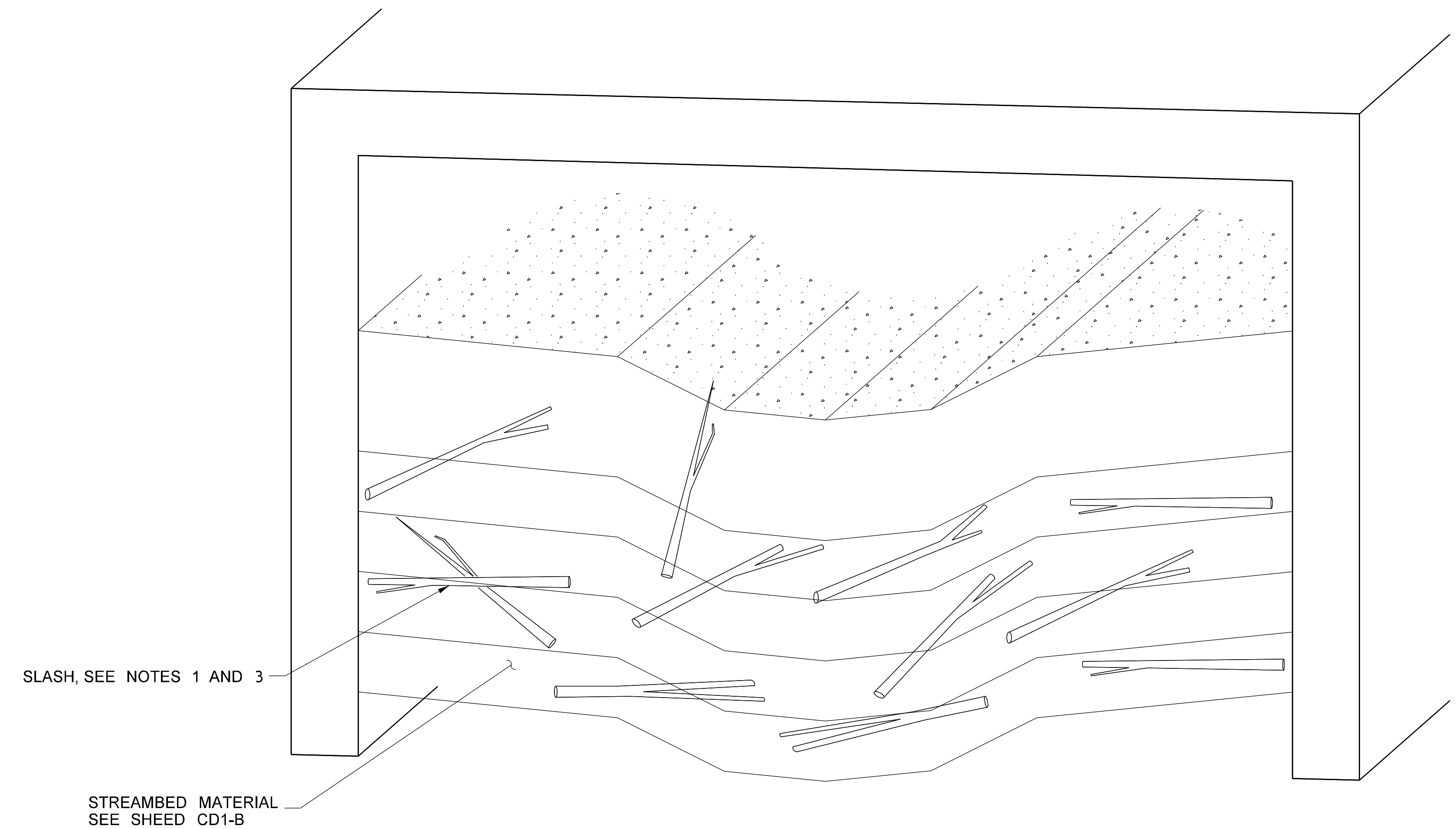


PLAN VIEW PER 1000 SQUARE FEET

NTS

NOTES

1. SLASH MATERIAL SHALL CONSIST OF SMALL LOGS OR BRANCHES THAT HAVE A MAXIMUM DIAMETER OF 4 INCHES AND A MAXIMUM LENGTH OF 6 FEET.
2. SLASH SHALL BE INSTALLED AT A DENSITY OF 30 PIECES PER 1000 SQUARE FEET PER LAYER.
3. SLASH IS INTENDED TO PROTRUDE INTO STREAMBED MATERIAL LAYERS ABOVE AND BELOW EACH SLASH LAYER. SLASH MAY NOT EXTEND ABOVE FINISHED GRADE BY MORE THAN 6 INCHES.



ISOMETRIC VIEW OF SLASH ORIENTATION

NTS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\19.17_TribToVanceCr\Design_CAD_Sheets\Preliminary_Design\US12MP19.17_F_DE_LWM_007.dgn

FILE NAME	c:\users\rhw\pw_wsdot\d0354379\US12MP19.17_F_DE_LWM_007.dgn			
TIME	2:27:31 PM			
DATE	10/24/2022			
PLOTTED BY	Rhw			
DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

DATE P.E. STAMP BOX

DATE P.E. STAMP BOX

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 19.17 UNNAMED TRIBUTARY TO VANCE CREEK

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

SLASH DETAILS

PLAN REF NO LWM9-C

SHEET OF SHEETS

Appendix E: Manning’s Calculations (Not Used)

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***US 12***		**Key piece volume**	***1.310***	*yd^3*
Stream name	*Vance*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*446*	*ft*	**Total wood vol./ft**	***0.3948***	*yd^3/ft stream*
Bankfull width	*12*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd^3/log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)
A	2.00	*40*	4.65	**yes**	yes	26	121.01	2.19
B	1.50	*30*	1.96	**yes**	yes	18	35.34	1.63
C	1.0	*20*	0.58	**no**	no	22	12.80	1.16
D	0.3	*6*	0.02	**no**	no	515	8.09	0.35
E			0.00				0.00	
F			0.00				0.00	
G			0.00				0.00	
H			0.00				0.00	
I			0.00				0.00	
J			0.00				0.00	
K			0.00				0.00	
L			0.00				0.00	
M			0.00				0.00	
N			0.00				0.00	
O			0.00				0.00	
P			0.00				0.00	

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	44	581	177.2
Targets	**15**	**52**	**176.1**

US 12 Unnamed Tributary to Vance Creek

Large Wood Structure Stability Analysis

TABLE OF CONTENTS

Date of Last Revision: September 16, 2022

Designer: Roxanne Wilcox

Reviewed by: Karen Comings, P.E.

Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center.

US 12 Unnamed Tributary to Vance Creek
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

US 12 Unnamed Tributary to Vance Creek
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Vance	11+45	247	12.50	0.20	26.0	457	150

US 12 Unnamed Tributary to Vance Creel
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Vance	11+45	**35.60**	Very coarse gravel	5	128.9	80.3	40

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

US 12 Unnamed Tributary to Vance
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Vance	11+45	**Gravel/cobble**	4	137.0	85.3	41

US 12 Unnamed Tributary to Vance Creek
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Coast**	Pseudotsuga menziesii var. menzi.	33.5	38.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

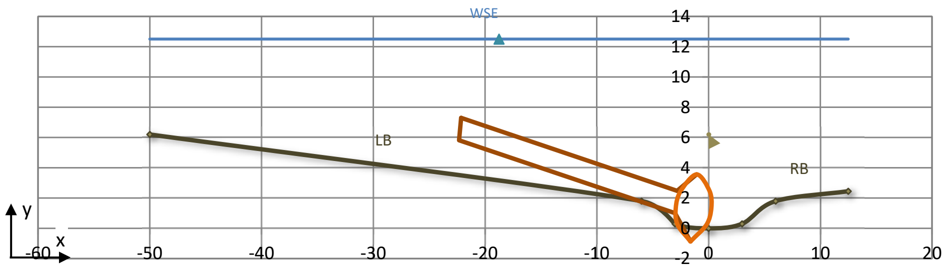
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

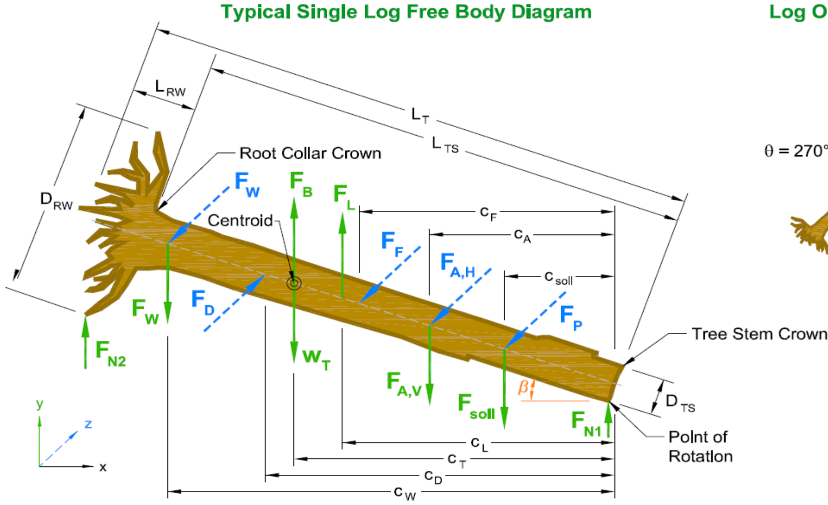


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

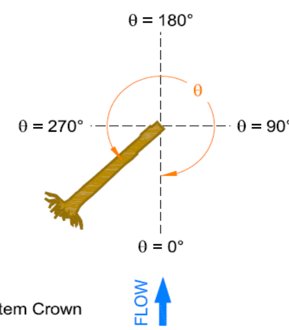
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	10.0	Root collar: Bottom	-3.00	1.00	-0.87	7.30	41.55

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.1	62.1	2,085	3,878
↓Thalweg	0.0	0.7	0.7	26	42
Total	49.0	13.8	62.8	2,110	3,920

Lift Force

C_{LT}	0.09
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	0	↑
W_T (lbf)	2,110	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,810	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.09	0.03	0.81	0.00	0.98	2

Horizontal Force Balance

F_D (lbf)	2	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	23.0	15.0	17.3	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	49,210
M_r (lbf)	26,480
FS_M	0.54 ⊗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

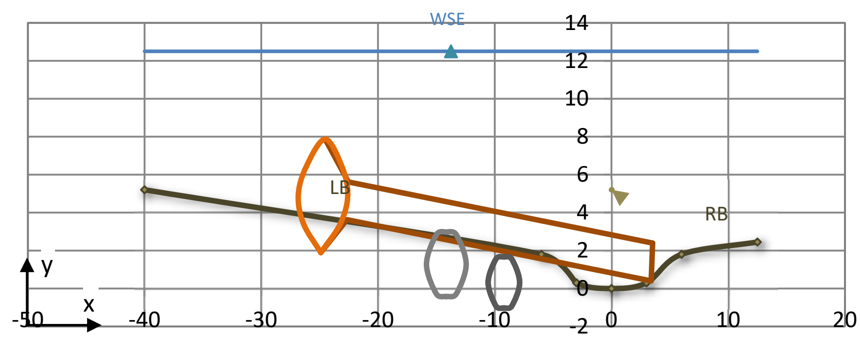
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

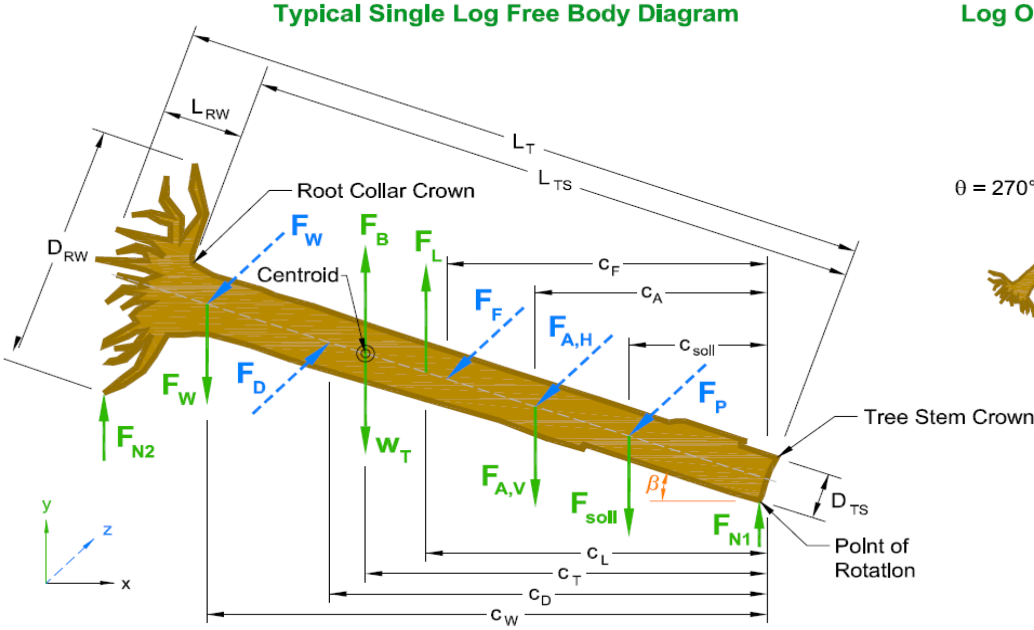


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

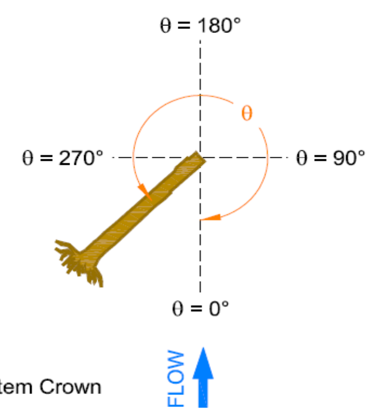
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	225.0	-5.0	Stem tip: Bottom	3.40	0.40	0.40	7.87	75.42

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.7	148.9	4,995	9,292
↓Thalweg	0.0	0.0	0.0	0	0
Total	116.2	32.7	148.9	4,995	9,292

Lift Force

C_{LT}	0.19
F_L (lbf)	1

Vertical Force Balance

F_B (lbf)	9,292
F_L (lbf)	1
W_T (lbf)	4,995
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	4,230
ΣF_V (lbf)	67
FS_V	0.99

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.17	0.02	0.76	0.00	1.10	3

457.05

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	14.30	0.87	0
Total	-	0	16.30	-	0

Horizontal Force Balance

F_D (lbf)	3
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	3
FS_H	0.00

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	20.5	20.0	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	157,537
M_r (lbf)	162,607
FS_M	1.03

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	18.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	18.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	3.40	25.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

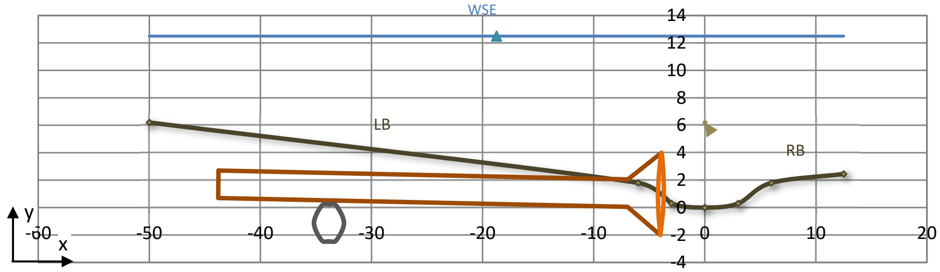
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

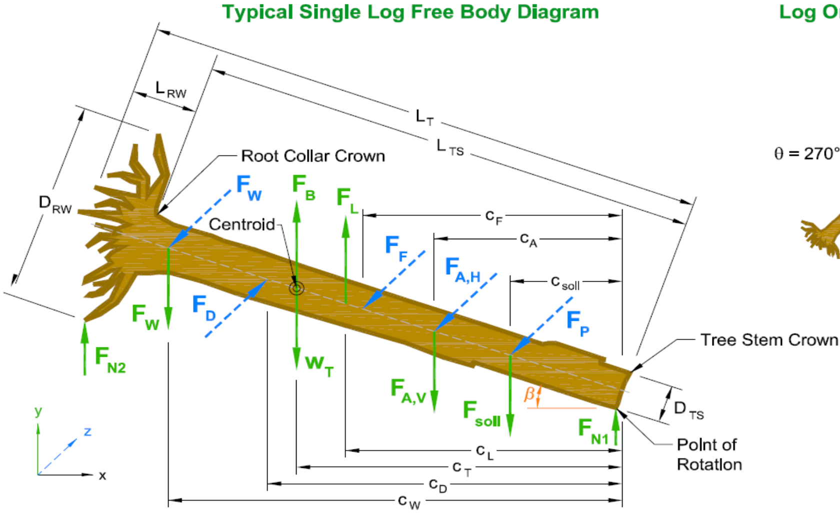


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

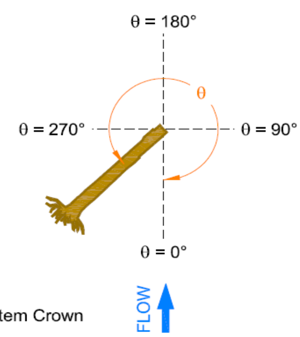
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	85.0	1.0	Rootwad: Bottom	-4.00	-2.00	-2.00	4.00	3.34

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	35.05	2.88	1.44

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	25.6	141.9	4,759	8,852
↓Thalweg	0.0	7.1	7.1	268	440
Total	116.2	32.7	148.9	5,027	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292
F_L (lbf)	0
W_T (lbf)	5,027
F_{soil} (lbf)	8,611
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	300
ΣF_V (lbf)	4,646
FS_V	1.50

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	100.9	100.9	8,611
Total	0.0	100.9	100.9	8,611

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.02	1.02	0.00	1.04	0

Horizontal Force Balance

F_D (lbf)	0
F_P (lbf)	20,730
F_F (lbf)	4,032
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	1,814
ΣF_H (lbf)	26,577
FS_H	197,721.55

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	186
Bank	4.81	20,730	40.00	0.87	3,846
Total	-	20,730	42.00	-	4,032

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.1	0.0	37.6	23.1	17.5	20.0	23.3

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	214,520
M_r (lbf)	945,033
FS_M	4.41

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	10.0	0.0	10.3	1,057	0	0	150	907
Deadman	2.70	10.0	0.0	10.3	1,057	0	0	150	907
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

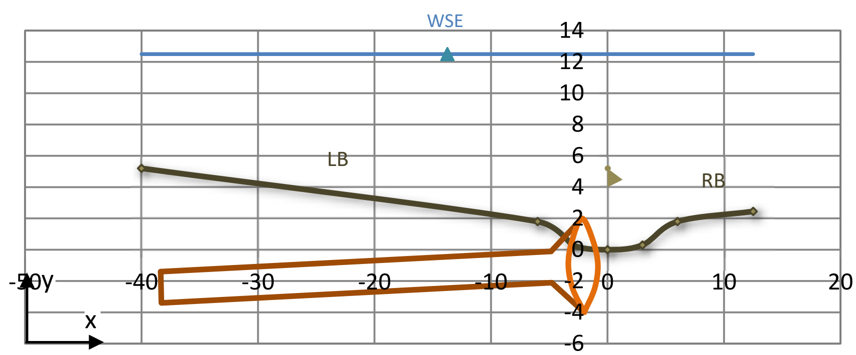
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Key Log	A Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

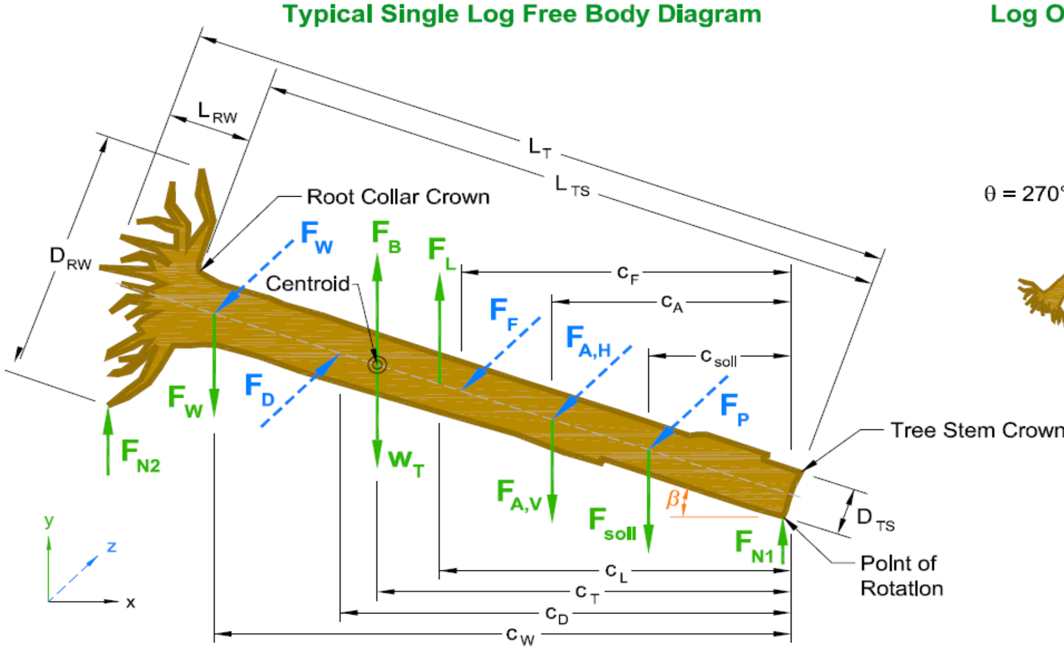


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

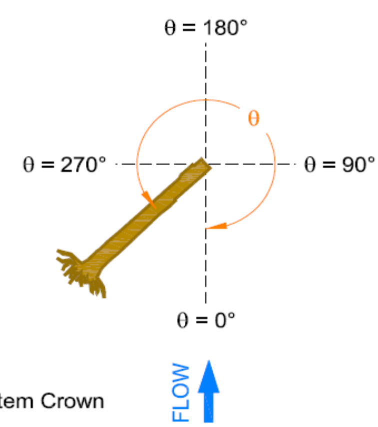
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	65.0	-2.0	Rootwad: Bottom	-2.00	-4.00	-4.00	2.00	3.49

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.96	0.32	0.27
Bank	Gravel/cobble	137.0	85.3	41.0	4	39.04	6.43	3.93

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	6.9	6.9	232	432
↓Thalweg	116.2	25.8	142.0	5,396	8,860
Total	116.2	32.7	148.9	5,628	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	
W_T (lbf)	5,628	↓
F_{soil} (lbf)	26,243	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	22,579	↓
FS_V	3.43	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.5	0.5	39
Bank	0.0	307.2	307.2	26,204
Total	0.0	307.7	307.7	26,243

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.02	1.21	0.00	1.22	0

Horizontal Force Balance

F_D (lbf)	0	→
F_P (lbf)	63,175	←
F_F (lbf)	19,580	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	82,755	←
FS_H	499,736.37	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	90	2.90	0.84	1,308
Bank	4.81	63,085	39.10	0.87	18,272
Total	-	63,175	42.00	-	19,580

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	158,786
M_r (lbf)	2,726,104
FS_M	17.17 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

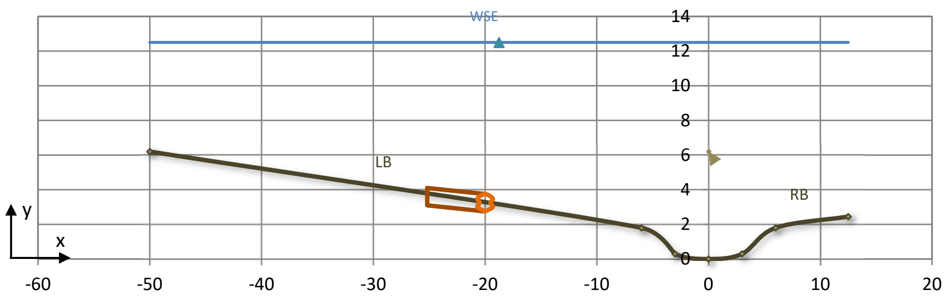
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

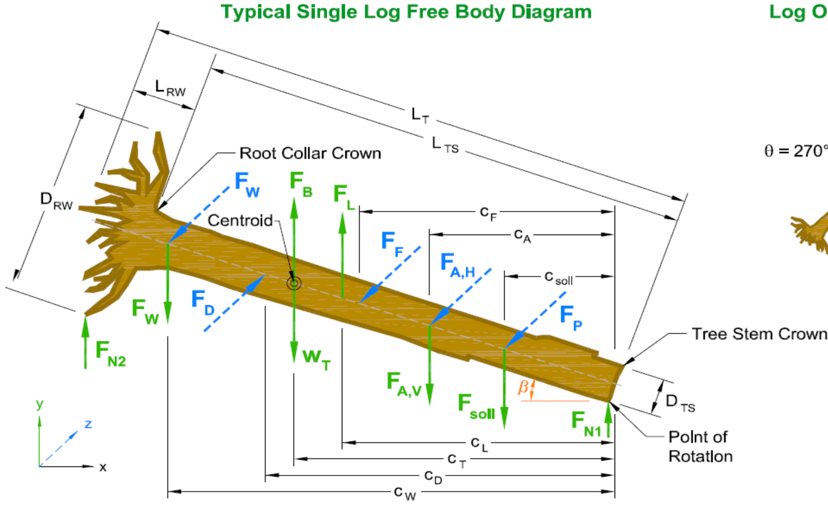


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

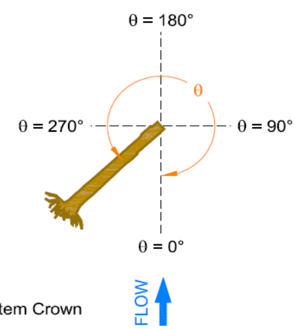
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	165.0	1.0	Root collar: Bottom	-20.00	2.75	2.75	4.10	2.40

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.04	0.62	0.00	0.62	0

Horizontal Force Balance

F_D (lbf)	0	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	0	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	20.00	0.87	0
Total	-	0	22.00	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,801
M_r (lbf)	5,269
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

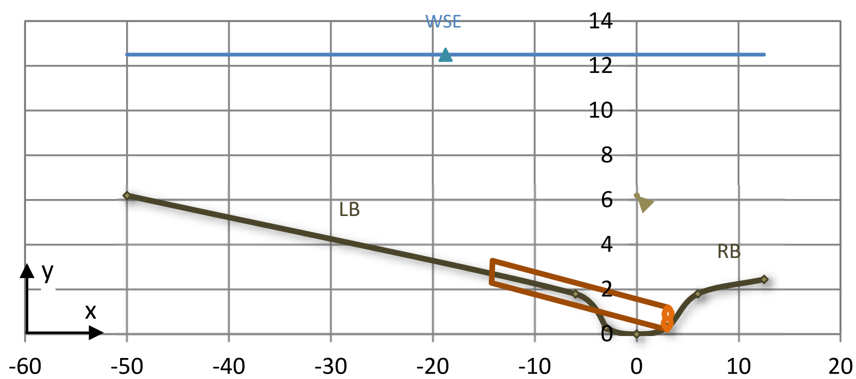
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

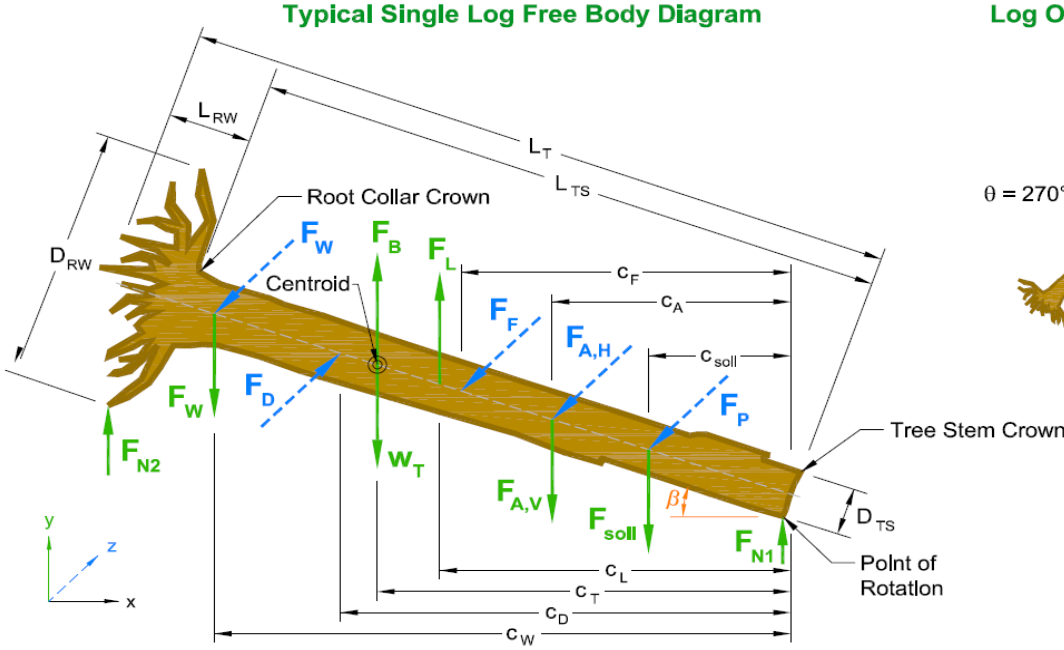


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

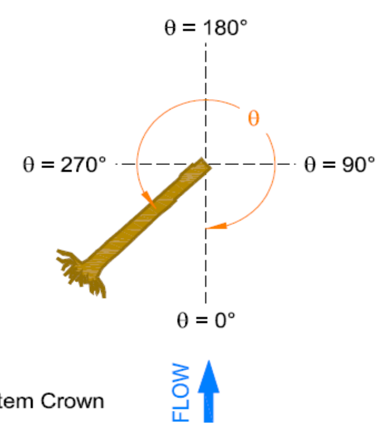
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	6.0	Root collar: Bottom	3.00	0.20	0.20	3.29	13.59

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.05
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.03	0.04	1.02	0.00	1.08	1

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.40	0.84	0
Bank	4.81	0	11.10	0.87	0
Total	-	0	13.50	-	0

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1	→
FS_H	0.00	⊗

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	15.7	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,754
M_r (lbf)	5,241
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster A Total Forces

Vertical Force Balance

Σ F_V (lbf)	1,863	↓

Horizontal Force Balance

Σ F_H (lbf)	26,571	←

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

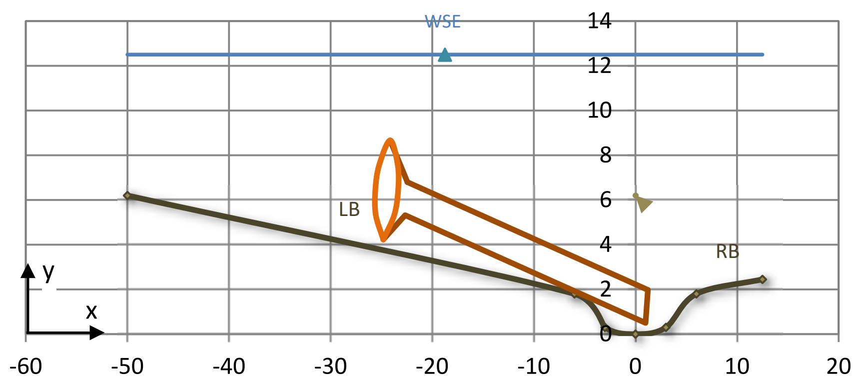
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

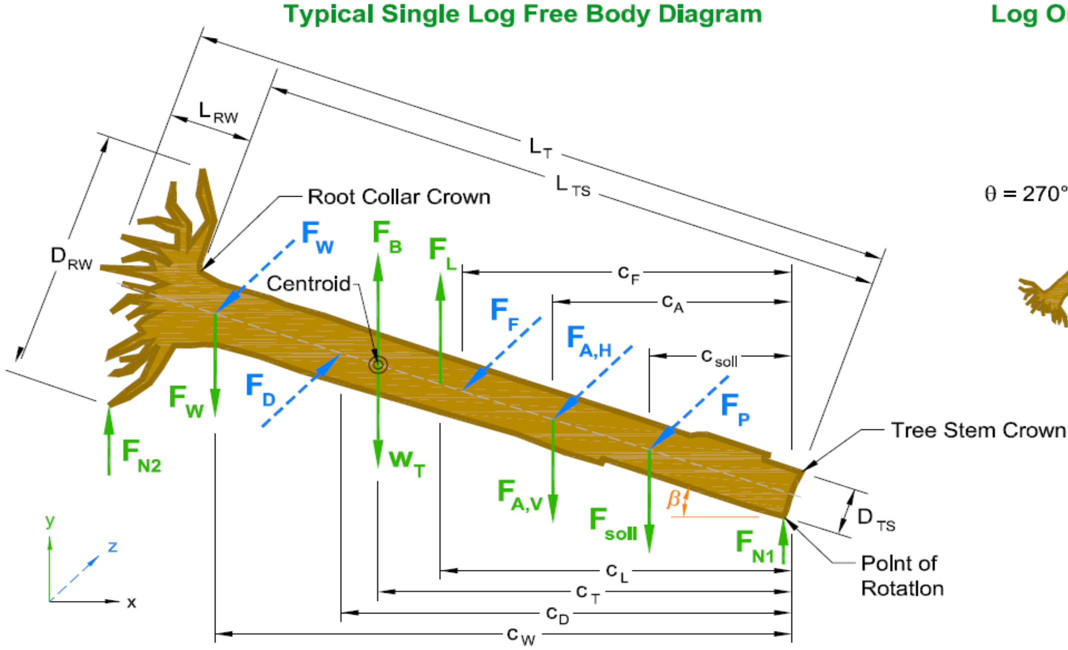


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

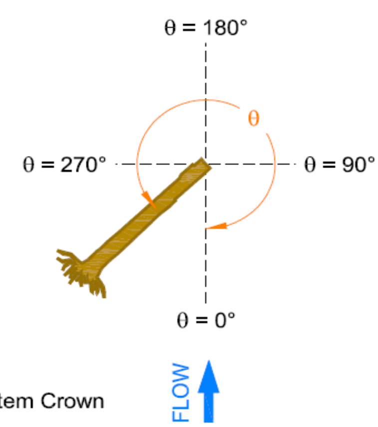
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	300.0	-10.0	Stem tip: Bottom	1.00	0.50	0.50	8.66	46.92

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.8	62.8	2,107	3,920
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	3,920

Lift Force

C_{LT}	0.06
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920
F_L (lbf)	0
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,813
FS_V	0.54

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.10	0.03	1.02	0.00	1.27	2

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	0

Horizontal Force Balance

F_D (lbf)	2
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	2
FS_H	0.00

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	9.2	15.0	17.2	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	49,289
M_r (lbf)	26,478
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

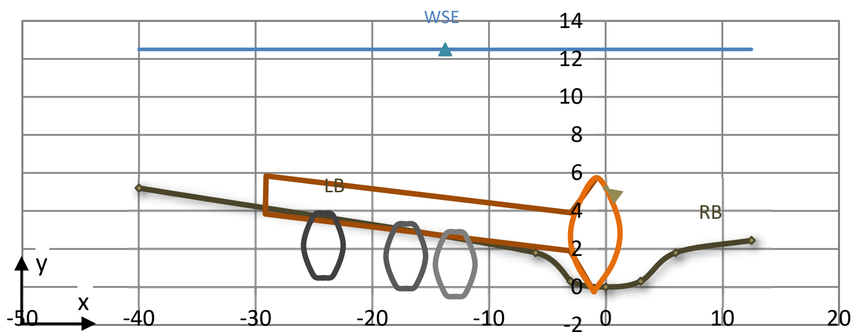
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

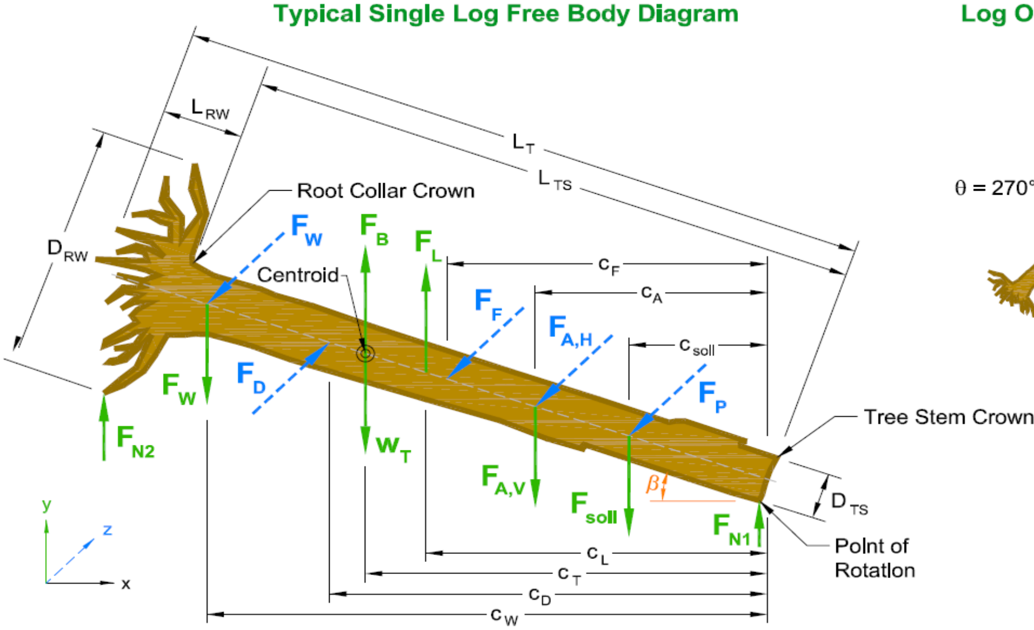


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

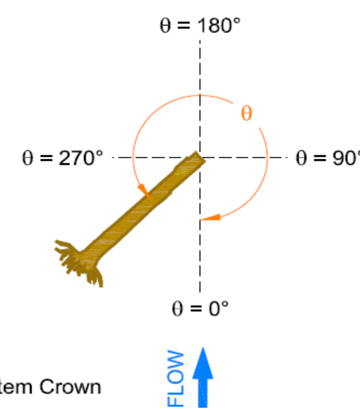
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	3.0	Rootwad: Bottom	-1.00	-0.25	-0.25	5.84	74.86

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.6	148.9	4,994	9,289
↓Thalweg	0.0	0.0	0.0	2	3
Total	116.2	32.7	148.9	4,996	9,292

Lift Force

C_{LT}	0.18
F_L (lbf)	1

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	1	↑
W_T (lbf)	4,996	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	6,346	↓
ΣF_V (lbf)	2,049	↓
FS_V	1.22	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.16	0.02	1.12	0.00	1.61	5

Horizontal Force Balance

F_D (lbf)	5	→
F_P (lbf)	0	
F_F (lbf)	1,773	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,769	←
FS_H	378.38	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	206
Bank	4.81	0	14.70	0.87	1,568
Total	-	0	16.70	-	1,773

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	24.8	20.0	23.0	0.0	7.3	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	157,942
M_r (lbf)	363,864
FS_M	2.30 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.40	7.0	0.0	20.6	2,115	0	0	2,115	0
Deadman	3.40	17.0	0.0	20.6	2,115	0	0	2,115	0
Deadman	3.40	23.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

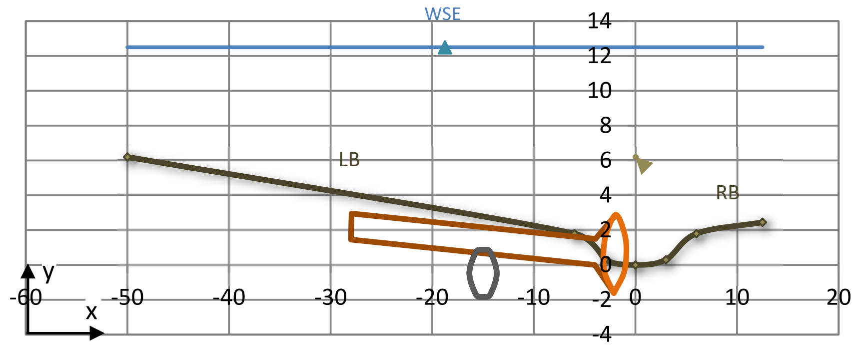
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

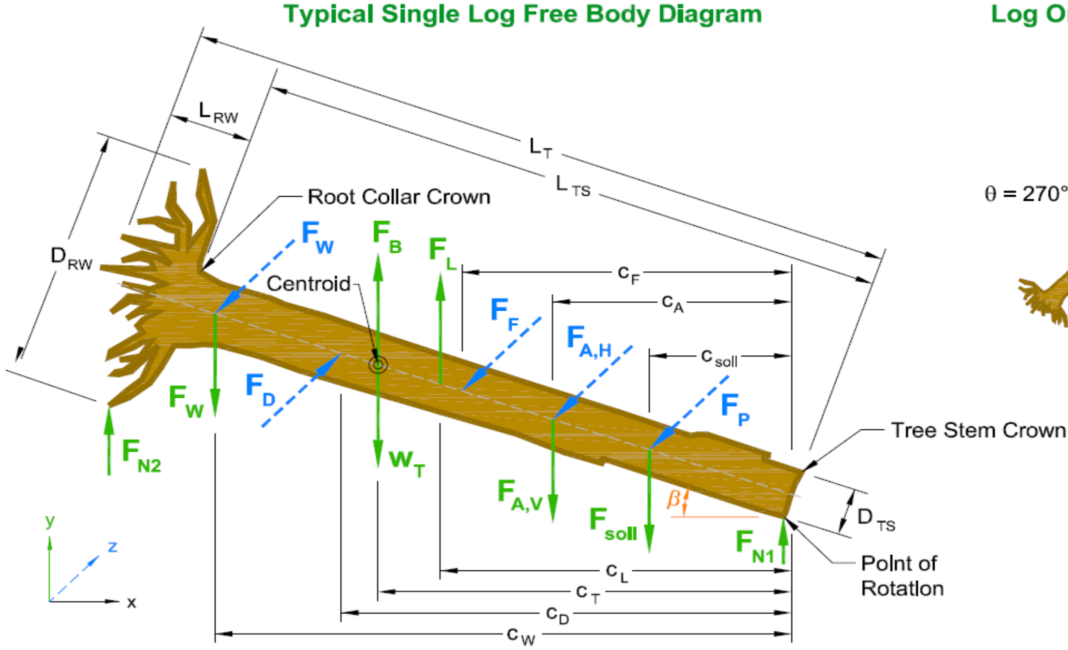


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

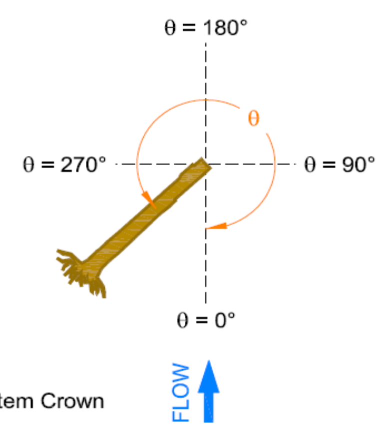
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	3.0	Root collar: Bottom	-4.00	0.00	-1.62	2.95	7.98

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	25.82	1.04	0.60

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	10.4	59.5	1,995	3,710
↓Thalweg	0.0	3.4	3.4	128	210
Total	49.0	13.8	62.8	2,122	3,920

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920
F_L (lbf)	0
W_T (lbf)	2,122
F_{soil} (lbf)	1,984
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	1,773
ΣF_V (lbf)	1,960
FS_V	1.50

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	23.3	23.3	1,984
Total	0.0	23.3	23.3	1,984

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.03	0.94	0.00	0.97	0

Horizontal Force Balance

F_D (lbf)	0
F_P (lbf)	4,777
F_F (lbf)	1,698
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	341
ΣF_H (lbf)	6,816
FS_H	22,730.09

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.13	0.84	161
Bank	4.81	4,777	28.87	0.87	1,537
Total	-	4,777	32.00	-	1,698

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	0.0	28.0	17.3	12.9	15.0	17.2

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	67,838
M_r (lbf)	230,812
FS_M	3.40

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	15.0	0.0	10.3	1,057	0	0	887	171
Deadman	2.70	15.0	0.0	10.3	1,057	0	0	887	171
								0	0

Spreadsheet developed by
Michael Rafferty, P.E.

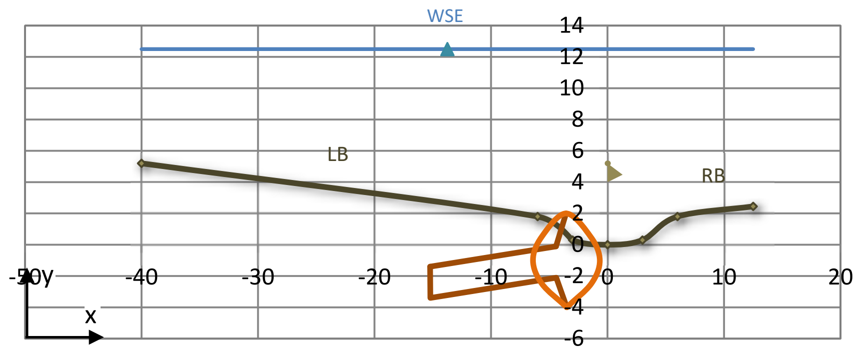
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Key Log	B Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

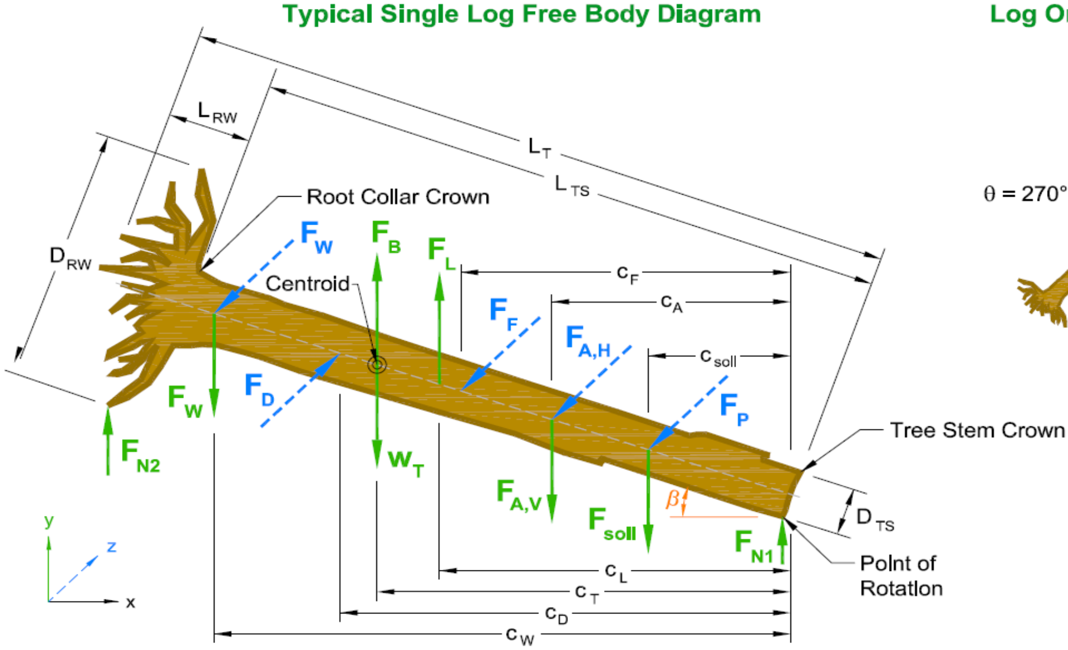


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

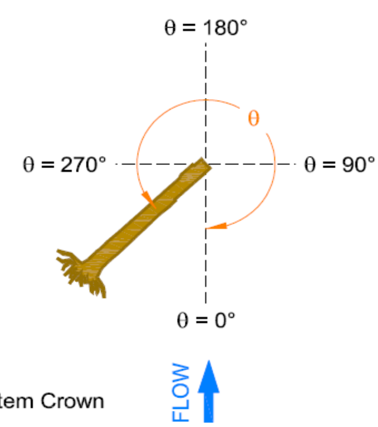
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	17.0	-2.0	Rootwad: Bottom	-3.50	-4.00	-4.00	2.00	7.89

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	40.00	4.12	2.73

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	6.9	6.9	232	432
↓Thalweg	116.2	25.8	142.0	5,396	8,860
Total	116.2	32.7	148.9	5,628	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292
F_L (lbf)	0
W_T (lbf)	5,628
F_{soil} (lbf)	18,667
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	15,003
FS_V	2.61

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	218.8	218.8	18,667
Total	0.0	218.8	218.8	18,667

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.02	1.24	0.00	1.28	0

Horizontal Force Balance

F_D (lbf)	0
F_P (lbf)	44,940
F_F (lbf)	13,020
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	57,959
FS_H	148,060.89

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	599
Bank	4.81	44,940	40.00	0.87	12,421
Total	-	44,940	42.00	-	13,020

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	158,795
M_r (lbf)	1,927,634
FS_M	12.14

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

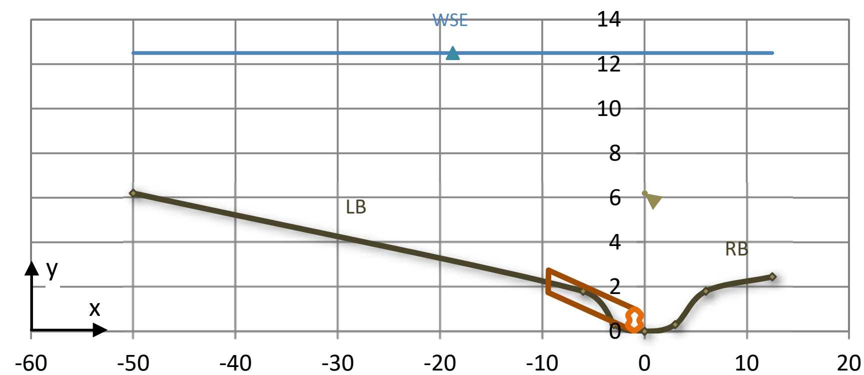
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)



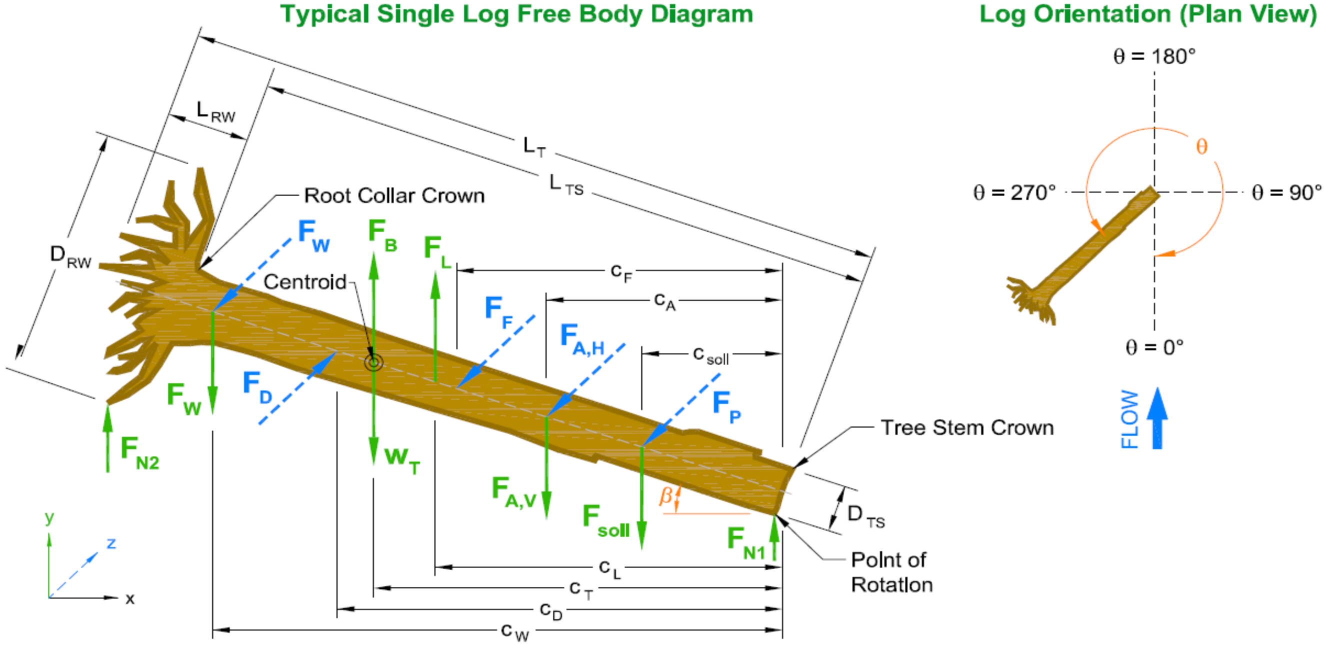
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	5.0	Root collar: Bottom	-1.00	0.00	0.00	2.74	5.46

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram

Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.07
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	✖

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.04	0.54	0.00	0.56	0

Horizontal Force Balance

F_D (lbf)	0	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	0	→
FS_H	0.00	✖

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	4.15	0.84	0
Bank	4.81	0	14.15	0.87	0
Total	-	0	18.30	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	16.0	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,766
M_r (lbf)	5,249
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

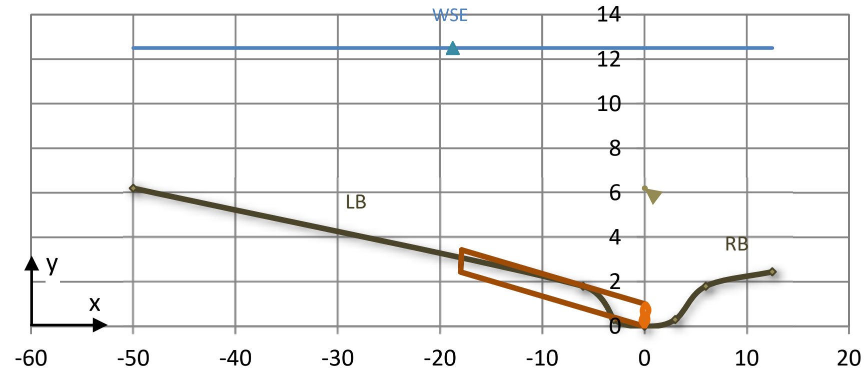
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

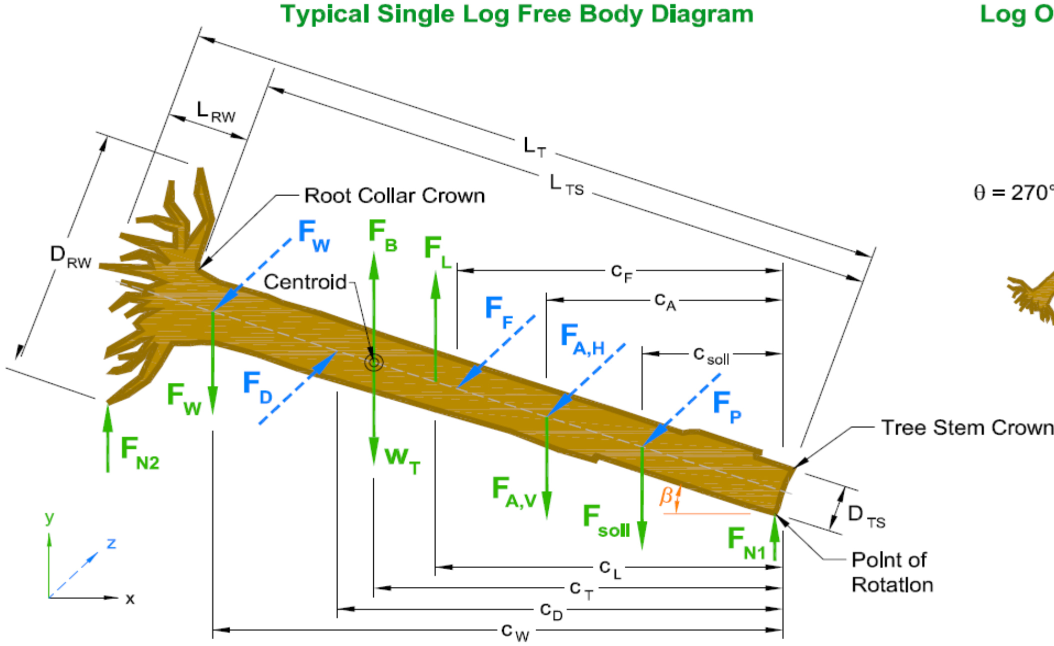


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

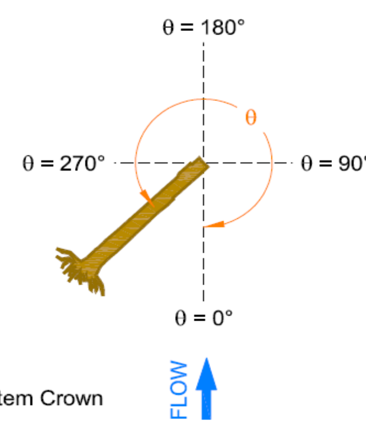
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	115.0	7.0	Root collar: Bottom	0.00	0.00	0.00	3.43	7.68

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.07
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.04	1.08	0.00	1.12	0

Horizontal Force Balance

F_D (lbf)	0	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	0	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.05	0.84	0
Bank	4.81	0	16.15	0.87	0
Total	-	0	18.20	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	18.1	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,732
M_r (lbf)	5,230
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster B Total Forces

Vertical Force Balance

ΣF_V (lbf)	1,289	↓

Horizontal Force Balance

ΣF_H (lbf)	8,582	←

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

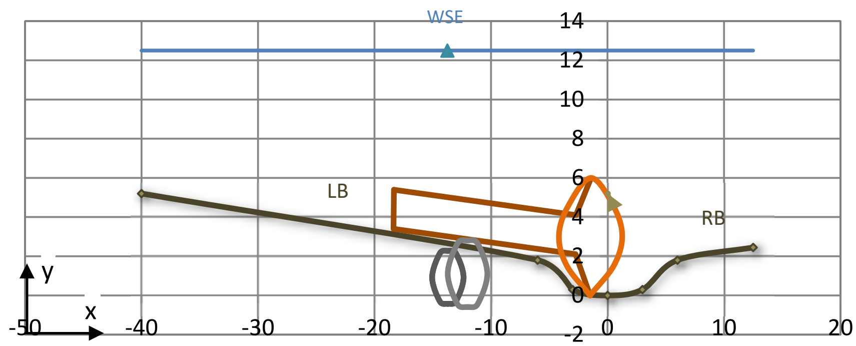
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

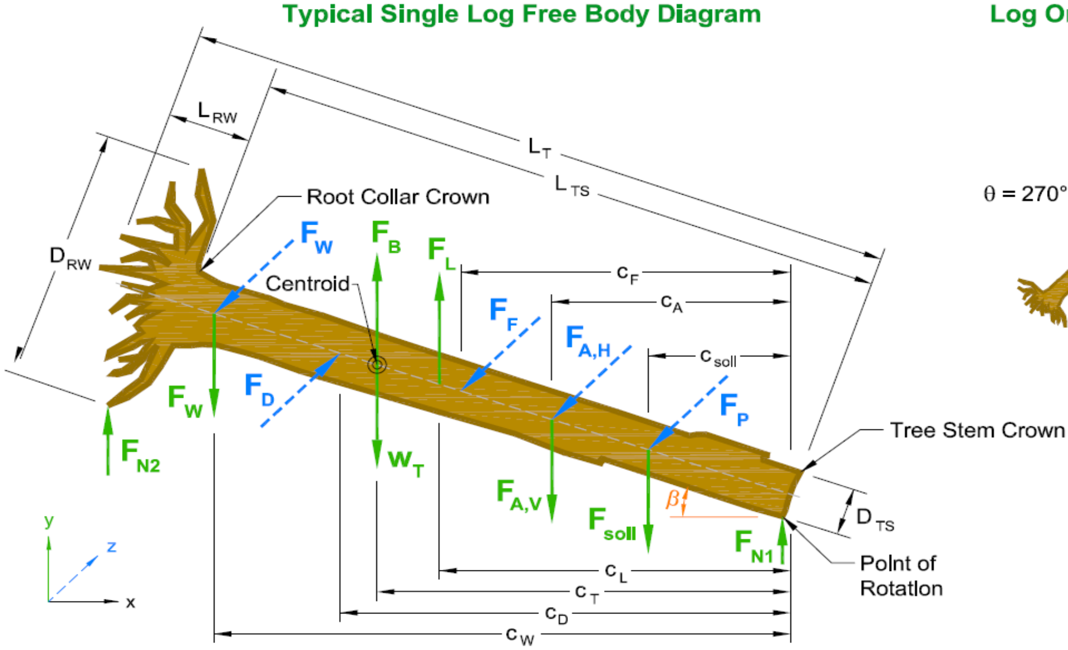


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

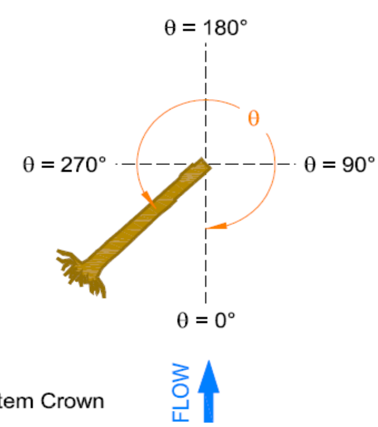
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	155.0	2.0	Rootwad: Bottom	-1.50	0.00	0.00	6.00	59.43

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.7	148.9	4,995	9,292
↓Thalweg	0.0	0.0	0.0	0	0
Total	116.2	32.7	148.9	4,995	9,292

Lift Force

C_{LT}	0.18
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	↑
W_T (lbf)	4,995	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	4,230	↓
ΣF_V (lbf)	67	↑
FS_V	0.99	

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.13	0.02	0.76	0.00	1.01	2

Horizontal Force Balance

F_D (lbf)	2	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2	→
FS_H	0.00	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	15.8	20.0	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	158,023
M_r (lbf)	199,062
FS_M	1.26

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	11.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	11.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	3.40	15.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

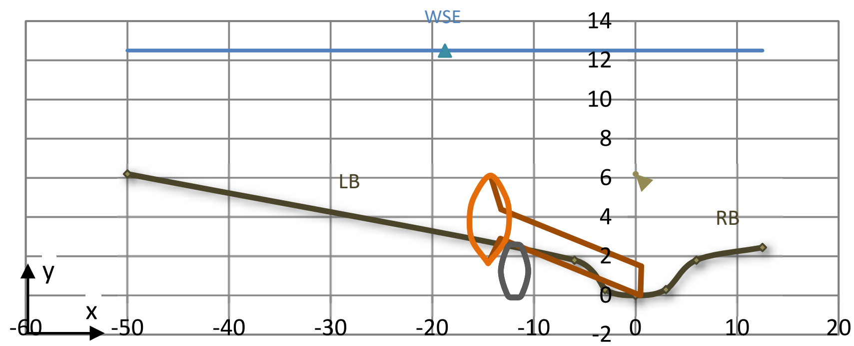
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

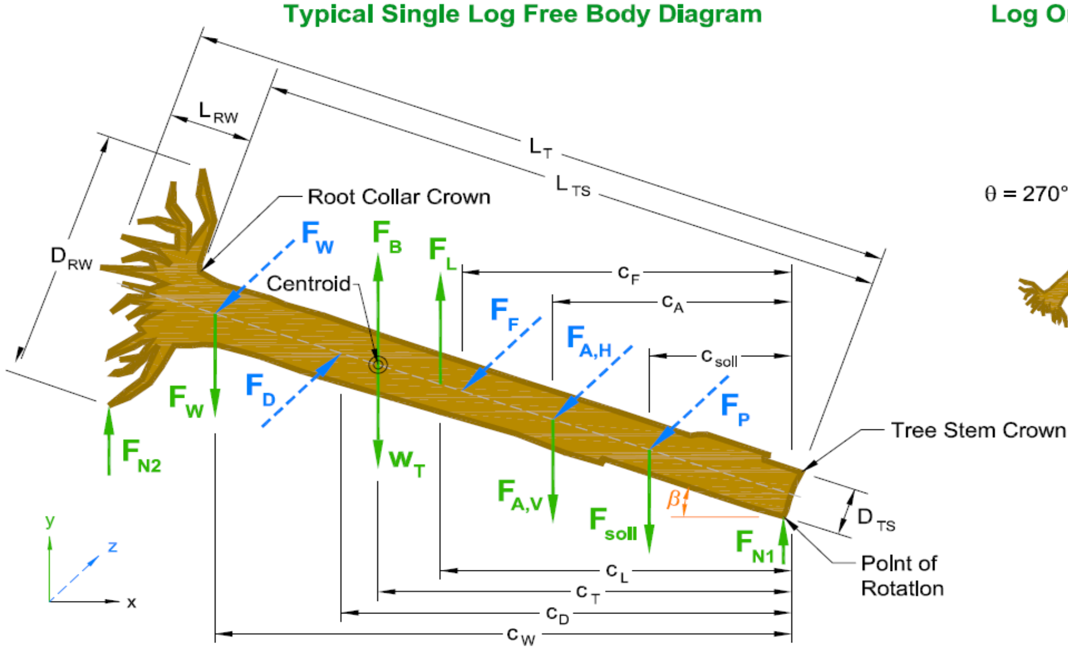


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

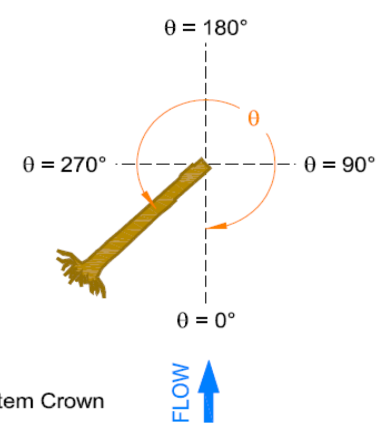
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	210.0	-6.0	Stem tip: Bottom	0.50	0.00	0.00	6.12	35.17

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.8	62.8	2,107	3,920
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	3,920

Lift Force

C_{LT}	0.19
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	0	↑
W_T (lbf)	2,107	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	2,115	↓
ΣF_V (lbf)	302	↓
FS_V	1.08	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.08	0.03	0.56	0.00	0.66	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	261	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	260	←
FS_H	288.09	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.38	0.84	47
Bank	4.81	0	10.50	0.87	214
Total	-	0	12.88	-	261

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	15.1	15.0	17.2	0.0	14.9	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	49,756	
M_r (lbf)	45,708	
FS_M	0.92	✗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	25.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	25.0	0.0	10.3	1,057	0	0	1,057	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

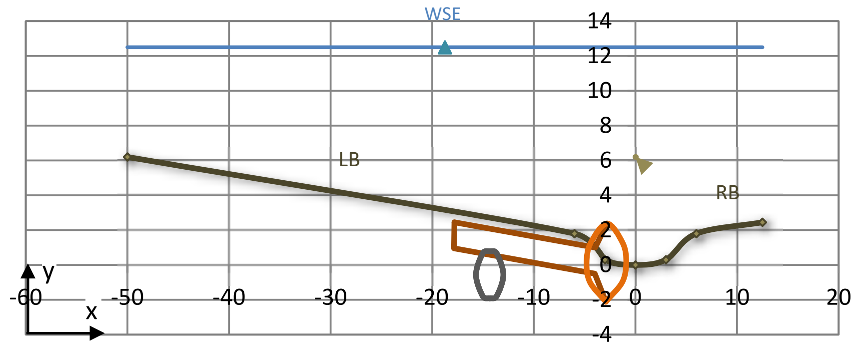
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

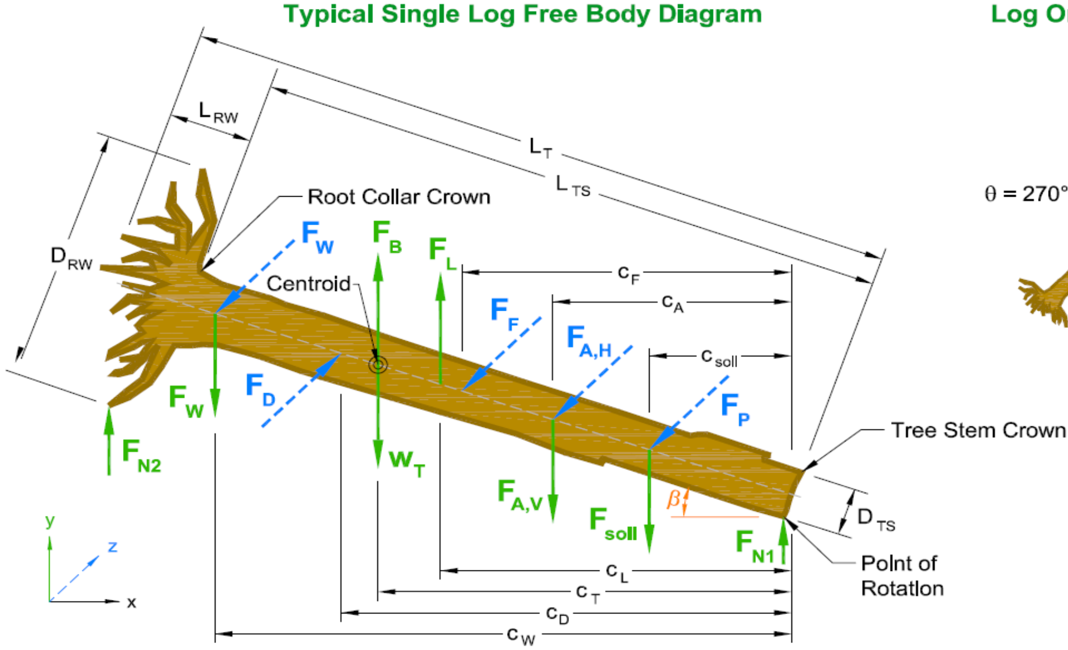


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

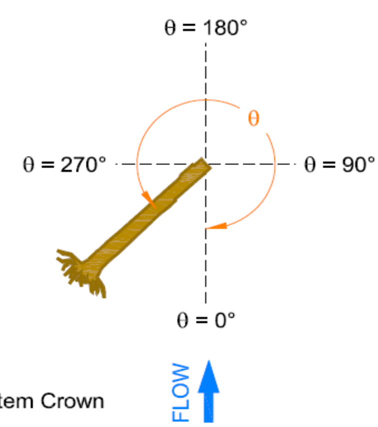
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	150.0	3.0	Root collar: Bottom	-4.00	-0.50	-2.12	2.45	7.90

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	26.65	0.59	0.53

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	47.0	7.9	54.9	1,841	3,424
↓Thalweg	2.0	5.9	7.9	302	496
Total	49.0	13.8	62.8	2,143	3,920

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	0	
W_T (lbf)	2,143	↓
F_{soil} (lbf)	1,808	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	1,930	↓
ΣF_V (lbf)	1,960	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	21.2	21.2	1,808
Total	0.0	21.2	21.2	1,808

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.03	0.77	0.00	0.80	0

Horizontal Force Balance

F_D (lbf)	0	→
F_P (lbf)	4,352	←
F_F (lbf)	1,699	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	185	←
ΣF_H (lbf)	6,236	←
FS_H	25,573.70	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.38	0.84	122
Bank	4.81	4,352	29.62	0.87	1,577
Total	-	4,352	32.00	-	1,699

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.4	0.0	28.4	17.4	13.3	15.0	17.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	68,024	
M_r (lbf)	207,661	
FS_M	3.05	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	7.0	0.0	10.3	1,057	0	0	965	93
Deadman	2.70	7.0	0.0	10.3	1,057	0	0	965	93
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

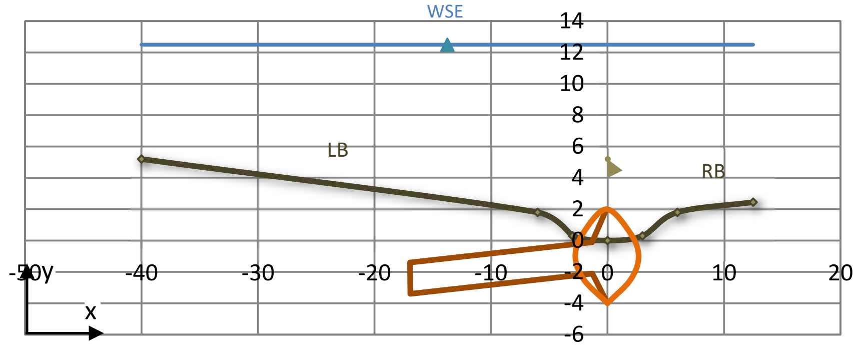
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.00	5.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

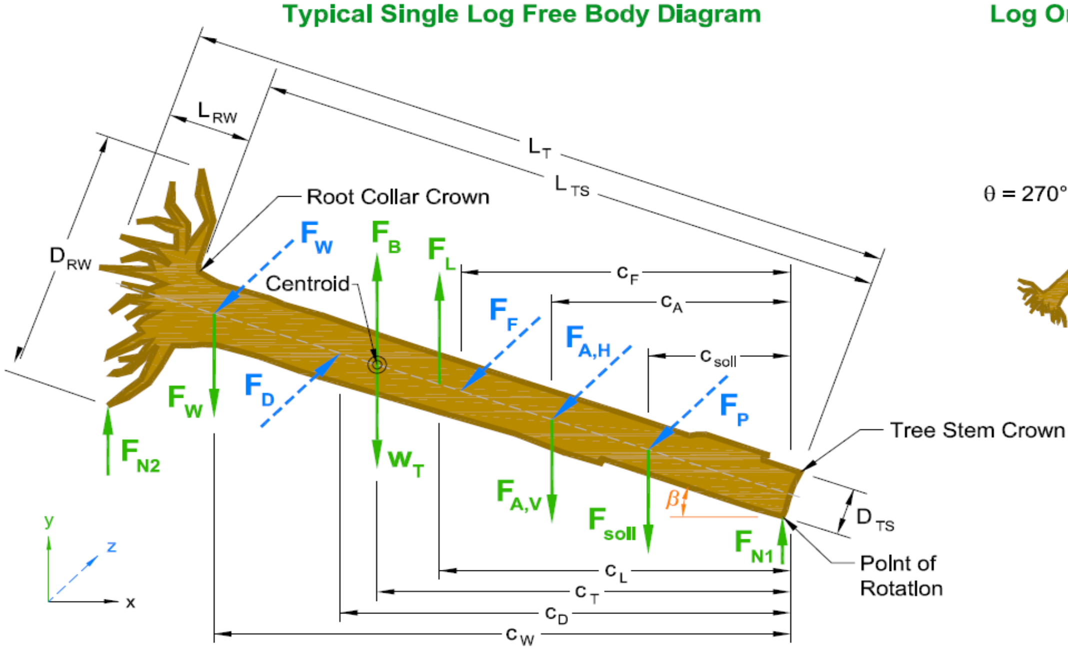


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

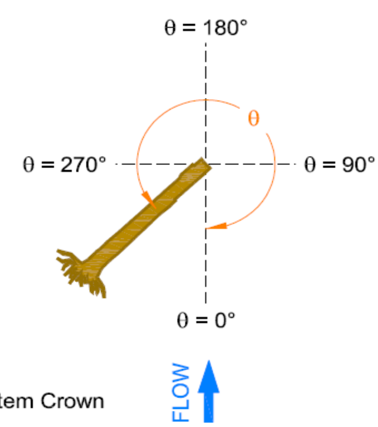
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	-2.0	Rootwad: Bottom	0.00	-4.00	-4.00	2.00	7.48

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	6.96	0.53	0.27
Bank	Gravel/cobble	137.0	85.3	41.0	4	33.04	4.29	2.89

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	6.9	6.9	232	432
↓Thalweg	116.2	25.8	142.0	5,396	8,860
Total	116.2	32.7	148.9	5,628	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292 ↑
F_L (lbf)	0
W_T (lbf)	5,628 ↓
F_{soil} (lbf)	16,602 ↓
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	12,938 ↓
FS_V	2.39 ✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	3.8	3.8	304
Bank	0.0	191.1	191.1	16,298
Total	0.0	194.8	194.8	16,602

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.02	1.24	0.00	1.27	0

Horizontal Force Balance

F_D (lbf)	0 →
F_P (lbf)	39,936 ←
F_F (lbf)	11,164 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	51,099 ←
FS_H	138,246.07 ✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	699	8.90	0.84	2,300
Bank	4.81	39,237	33.10	0.87	8,863
Total	-	39,936	42.00	-	11,164

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	158,794
M_r (lbf)	1,707,967
FS_M	10.76 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

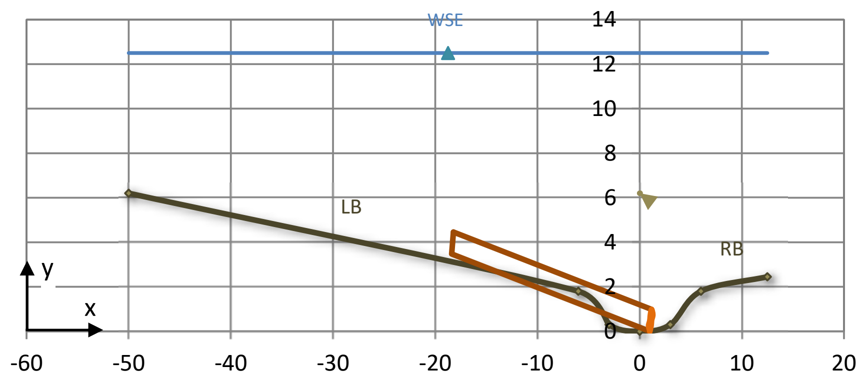
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

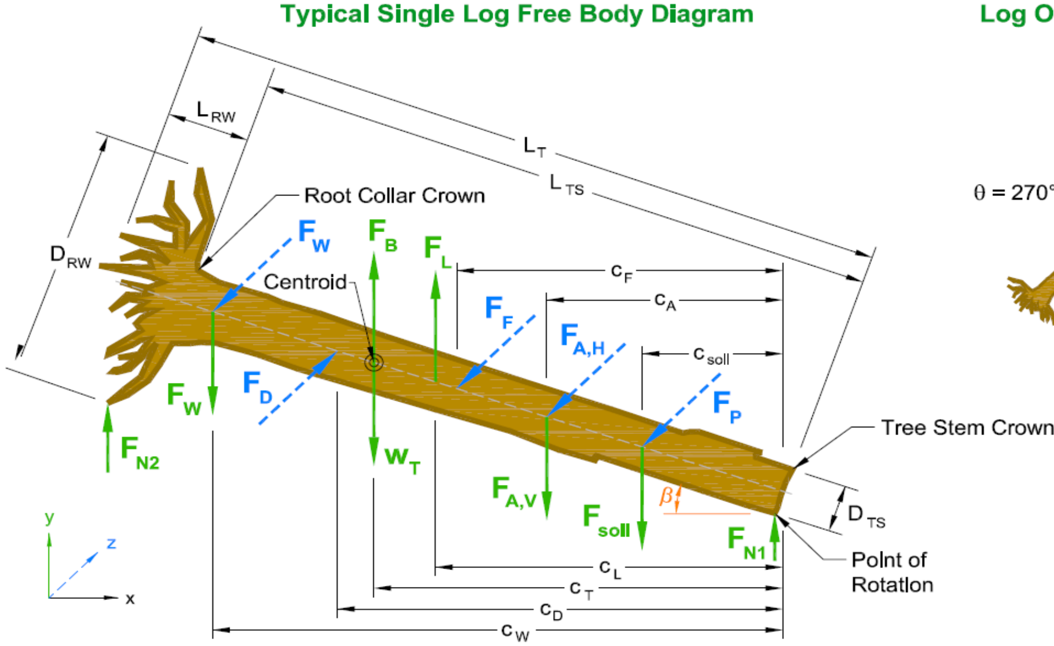


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

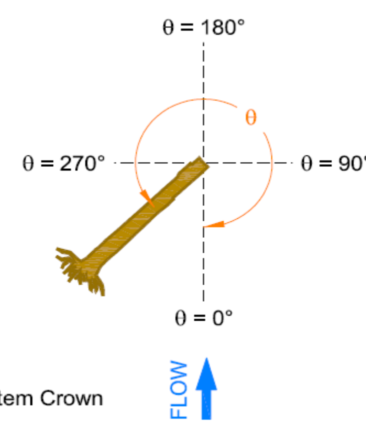
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	100.0	10.0	Root collar: Bottom	1.00	0.00	0.00	4.46	17.53

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.13
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.04	0.04	1.10	0.00	1.19	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.45	0.84	0
Bank	4.81	0	8.40	0.87	0
Total	-	0	10.85	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	9.5	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,662
M_r (lbf)	5,189
FS_M	0.54 ⊗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by
Michael Rafferty, P.E.

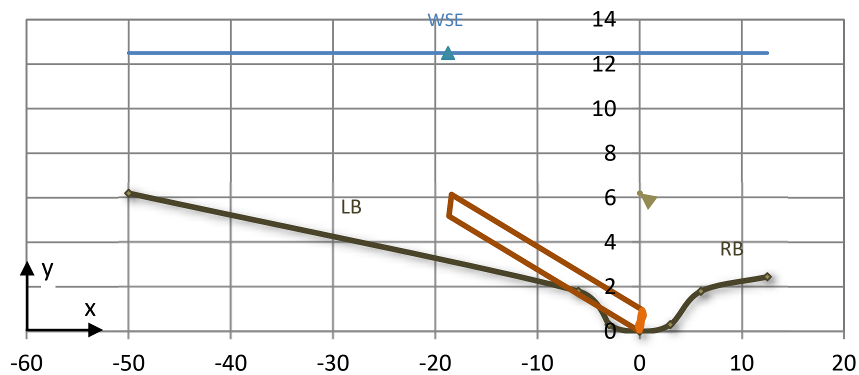
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Vance	Rootwad	Left bank	Straight	11+45	12.50	5.77	0.20

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.20
Top LB	-6.00	1.80
Toe LB	-3.00	0.30
Thalweg	0.00	0.00
Toe RB	3.00	0.30
Top RB	6.00	1.80
Fldpln RB	12.50	2.45

Proposed Cross-Section and Structure Geometry (Looking D/S)

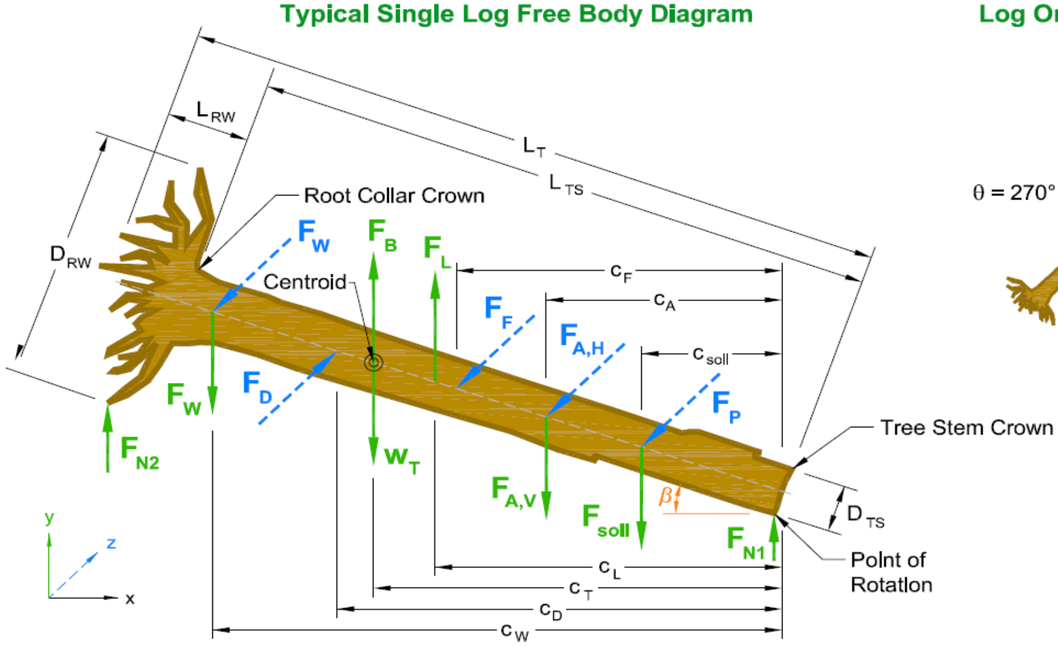


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

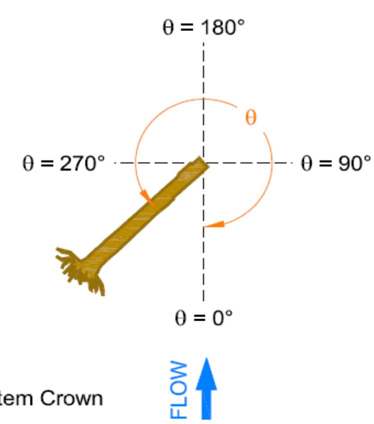
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	105.0	15.0	Root collar: Bottom	0.00	0.00	0.00	6.14	19.29

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.9	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.09
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	0	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	453	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.04	0.04	1.13	0.00	1.23	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.05	0.84	0
Bank	4.81	0	0.70	0.87	0
Total	-	0	2.75	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	14.8	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,477	
M_r (lbf)	5,090	
FS_M	0.54	⊗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Vance Creek

Spreadsheet developed by Michael Rafferty, P.E.

Cluster C Total Forces

Vertical Force Balance

ΣF_V (lbf)	1,288	↓

Horizontal Force Balance

ΣF_H (lbf)	6,492	←

US 12 Unnamed Tributary to Vance Creek
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 125 1806W34G

Stream Name:

Drainage Area: 61 ac

Projected mean percent change in bankfull flow:

2040s: 12.3%

2080s: 16.1%

Projected mean percent change in bankfull width:

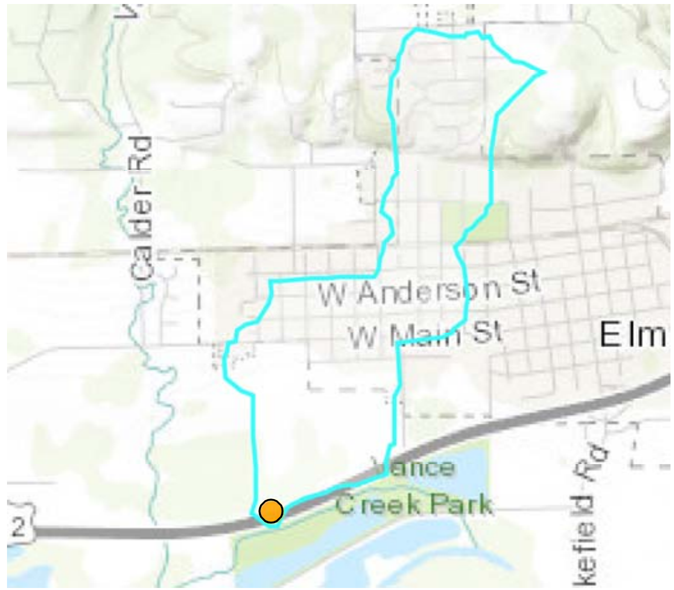
2040s: 6%

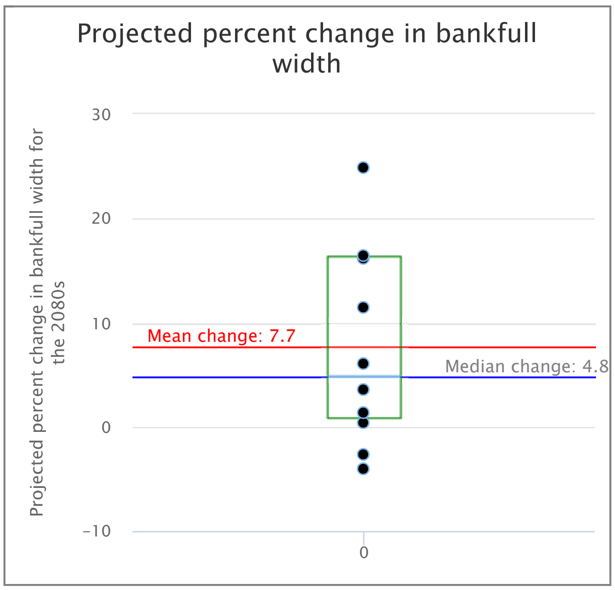
2080s: 7.7%

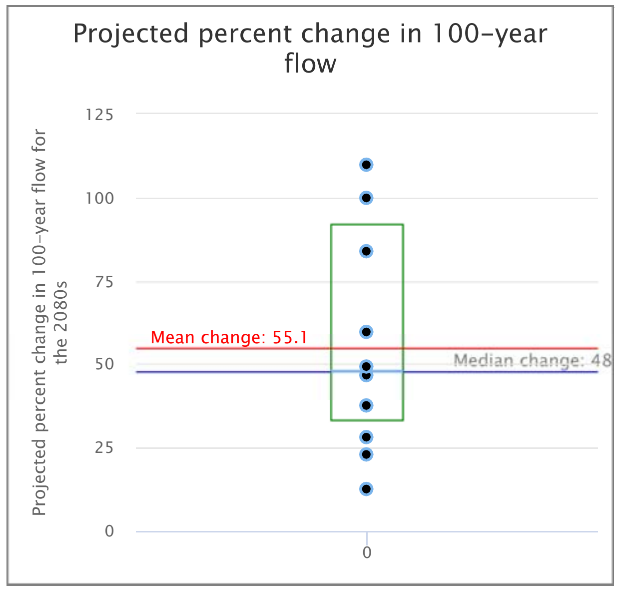
Projected mean percent change in 100-year flood:

2040s: 38.3%

2080s: 55.1%







Black dots are projections from 10 separate models

The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

Appendix H: SRH-2D Model Results

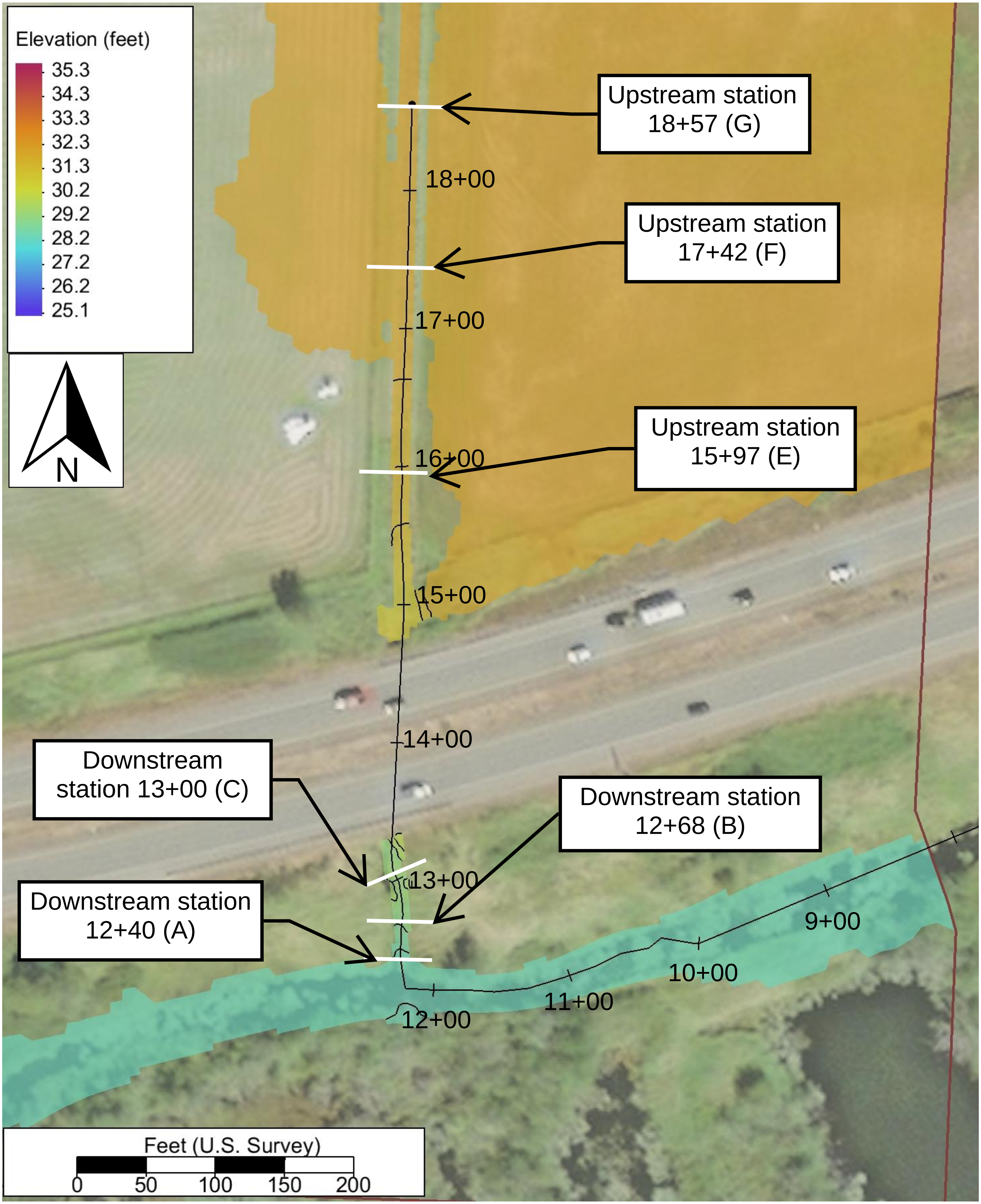


Figure H.1: Existing conditions 2-year Vance, low flow Chehalis water surface elevation

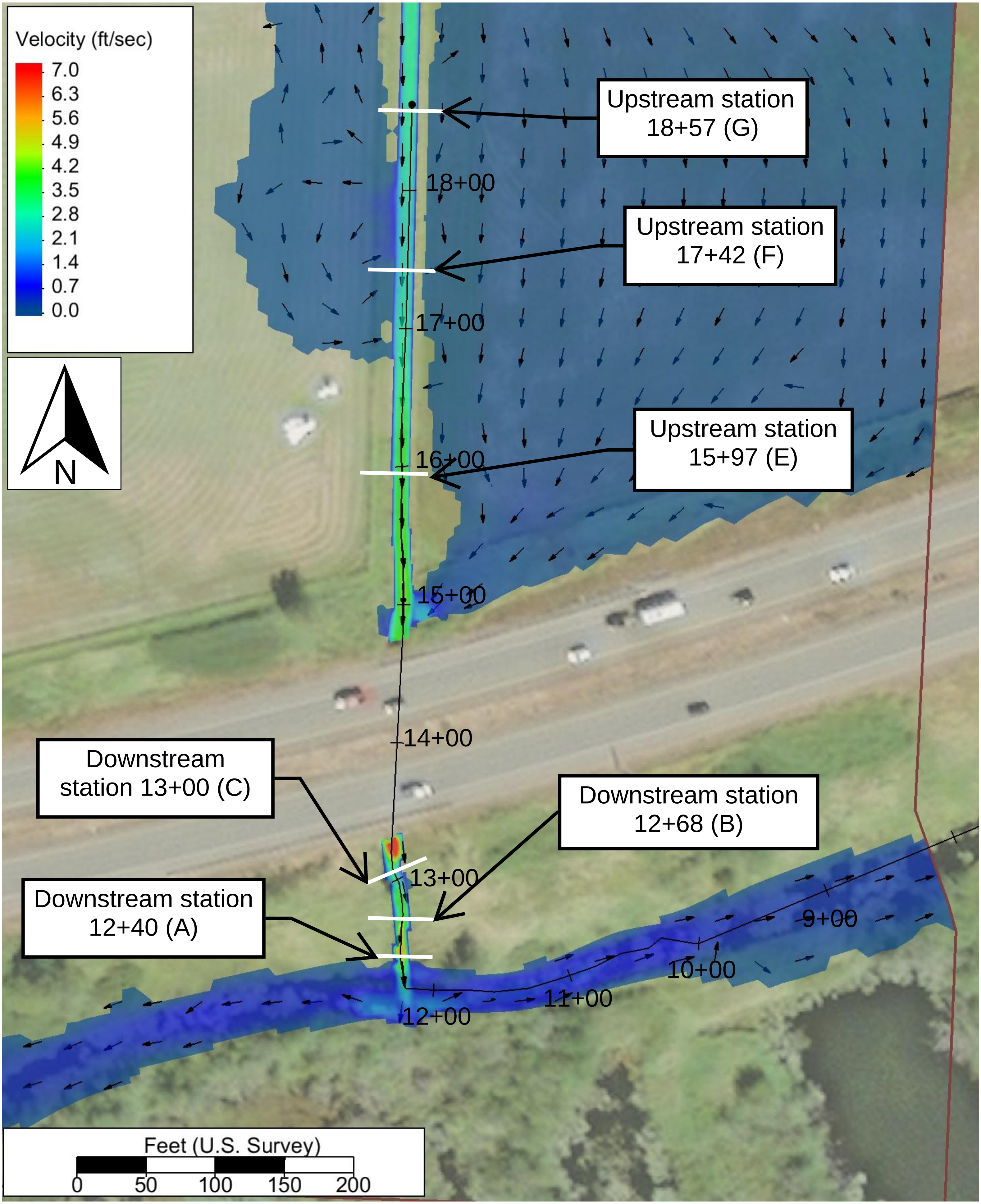


Figure H.2: Existing conditions 2-year Vance, low flow Chehalis velocity

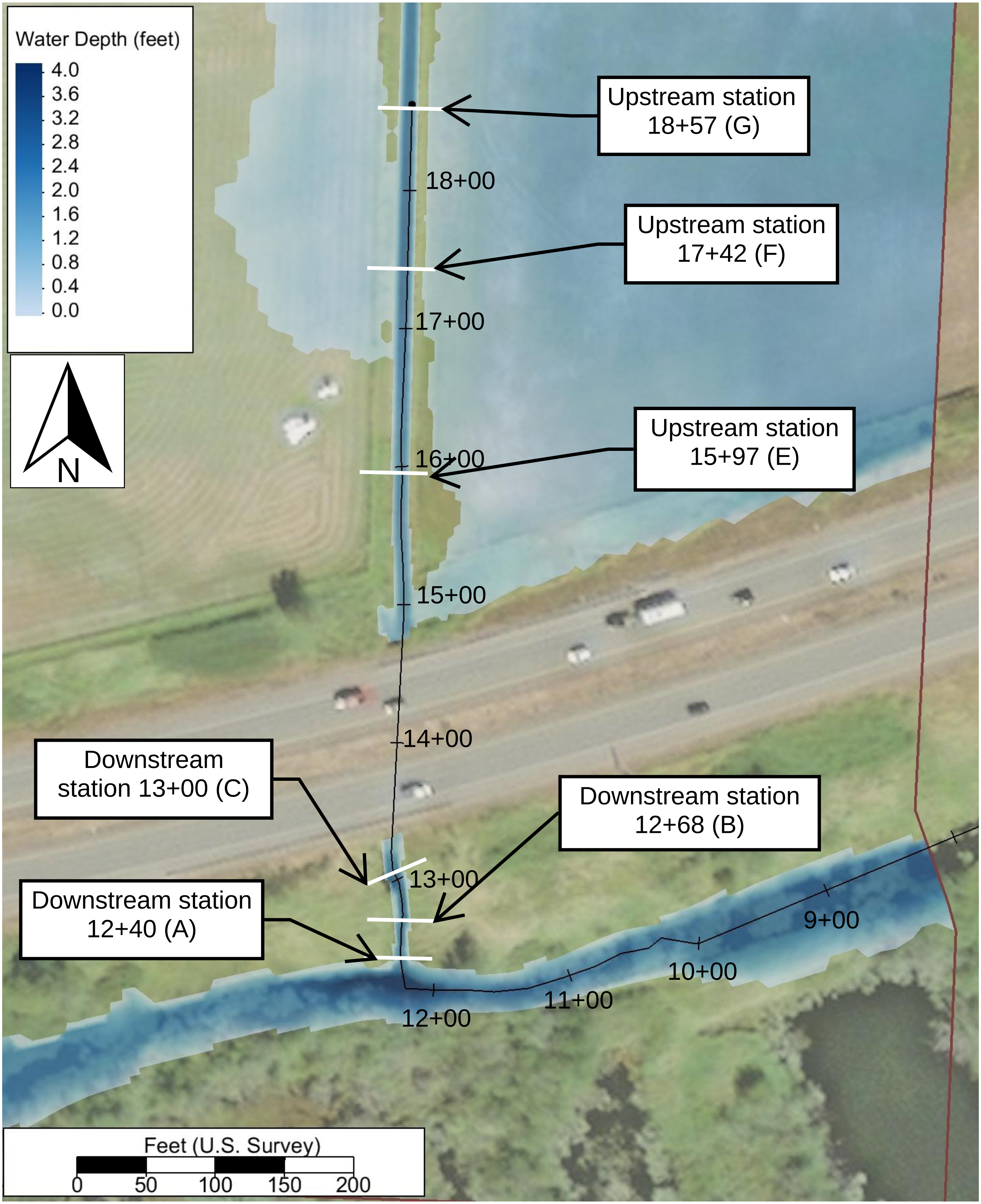


Figure H.3: Existing conditions 2-year Vance, low flow Chehalis water depth

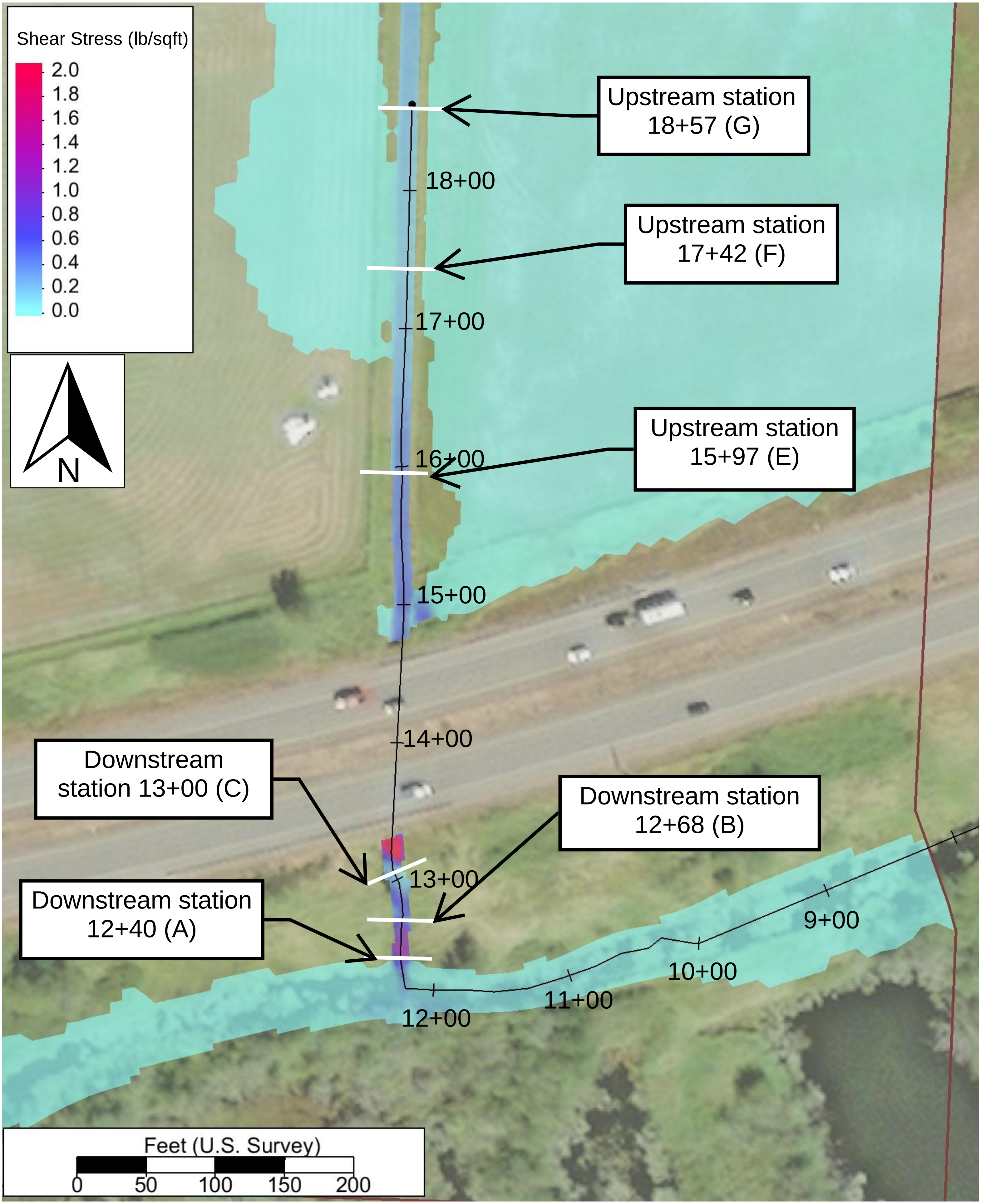


Figure H.4: Existing conditions 2-year Vance, low flow Chehalis shear stress

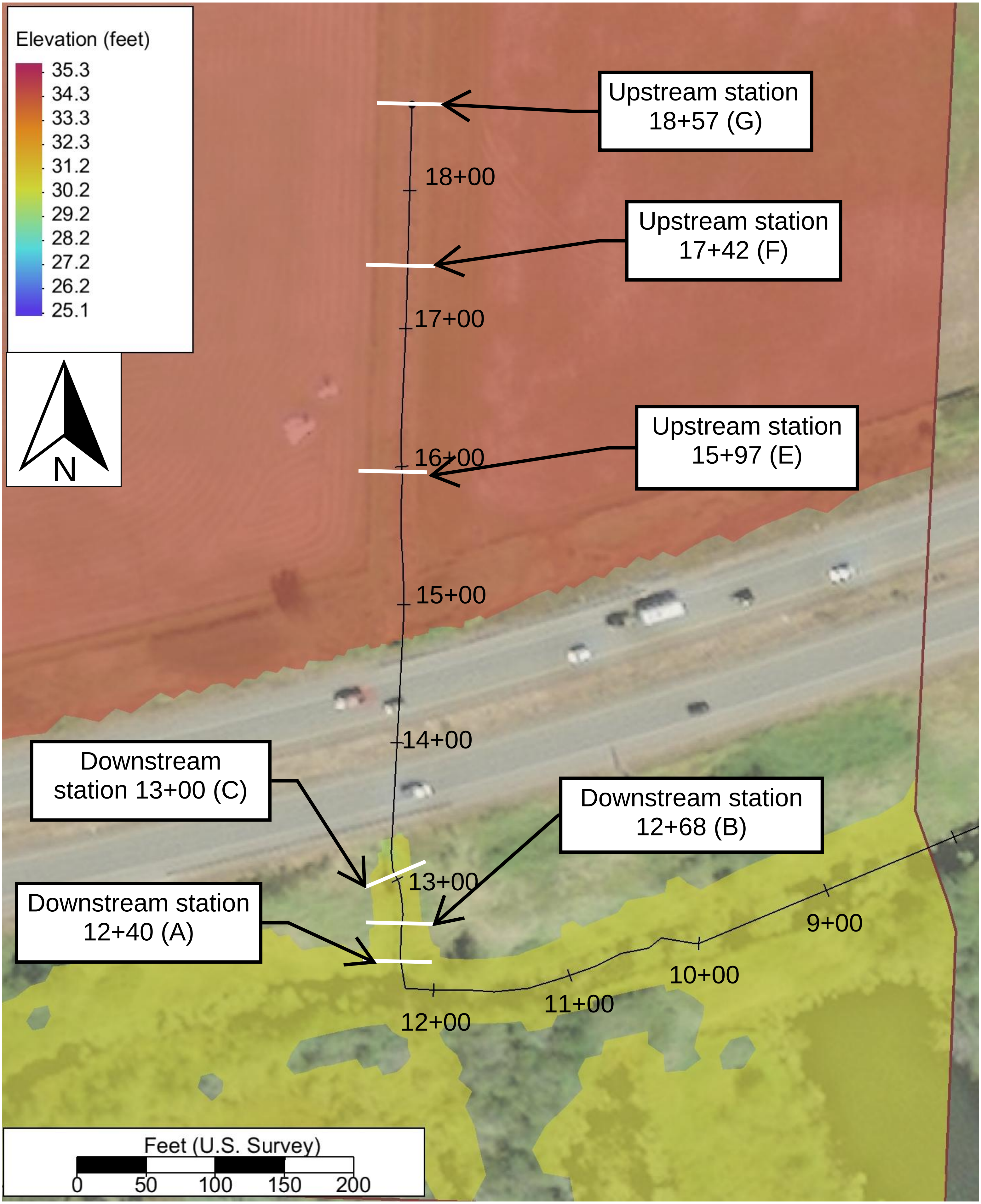


Figure H.5: Existing conditions 100-year Vance, low flow Chehalis water surface elevation

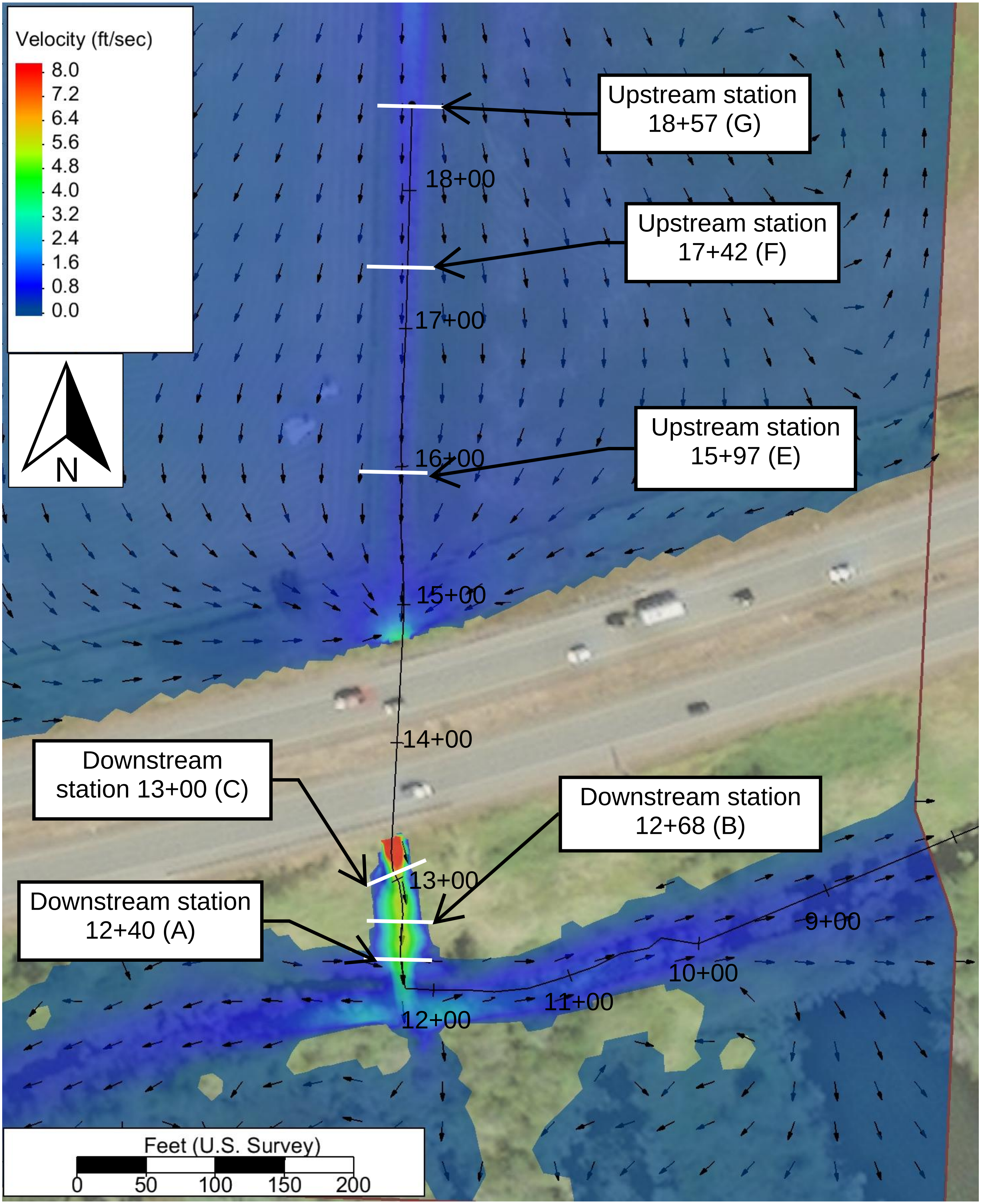


Figure H.6: Existing conditions 100-year Vance, low flow Chehalis velocity

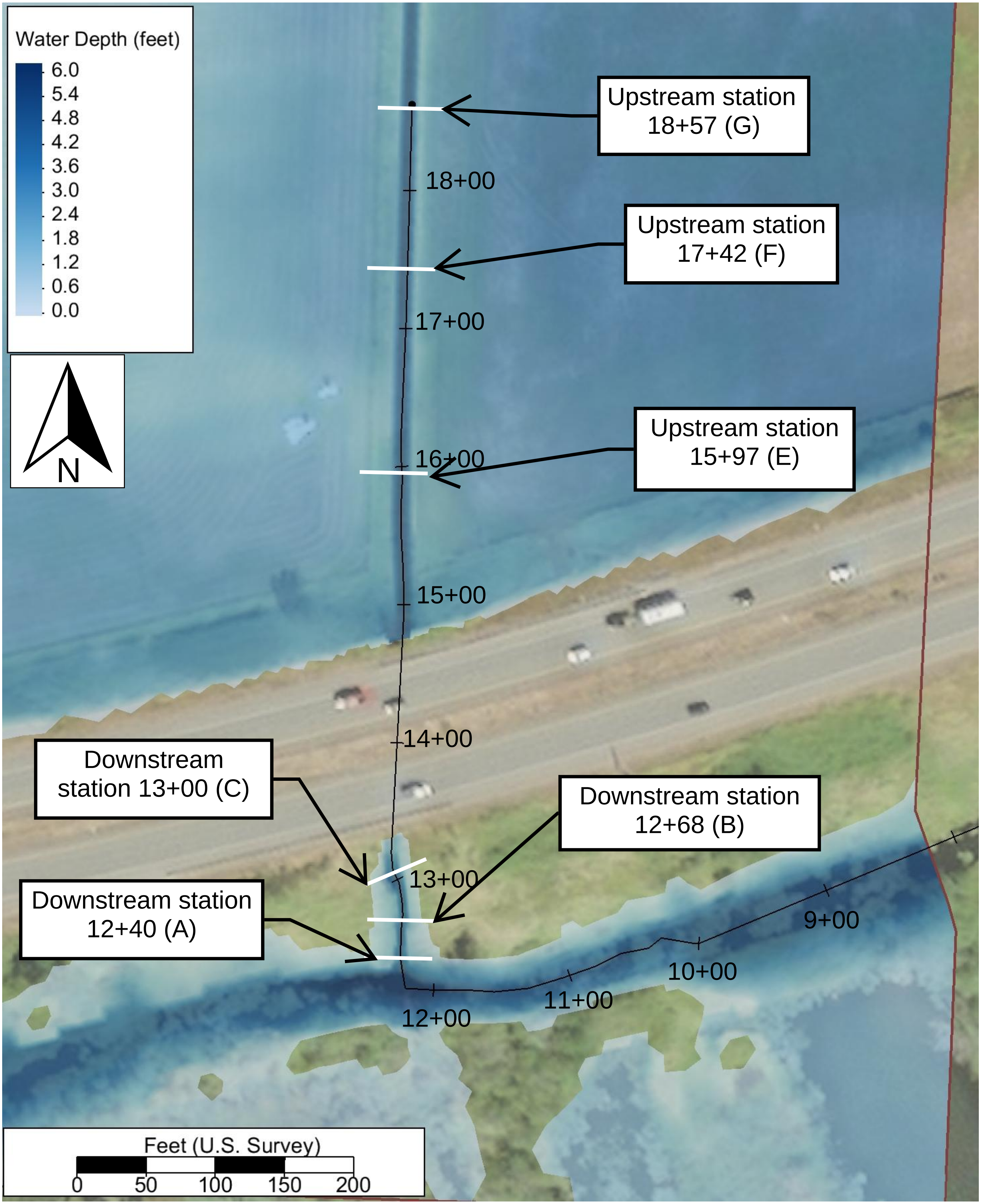


Figure H.7: Existing conditions 100-year Vance, low flow Chehalis water depth

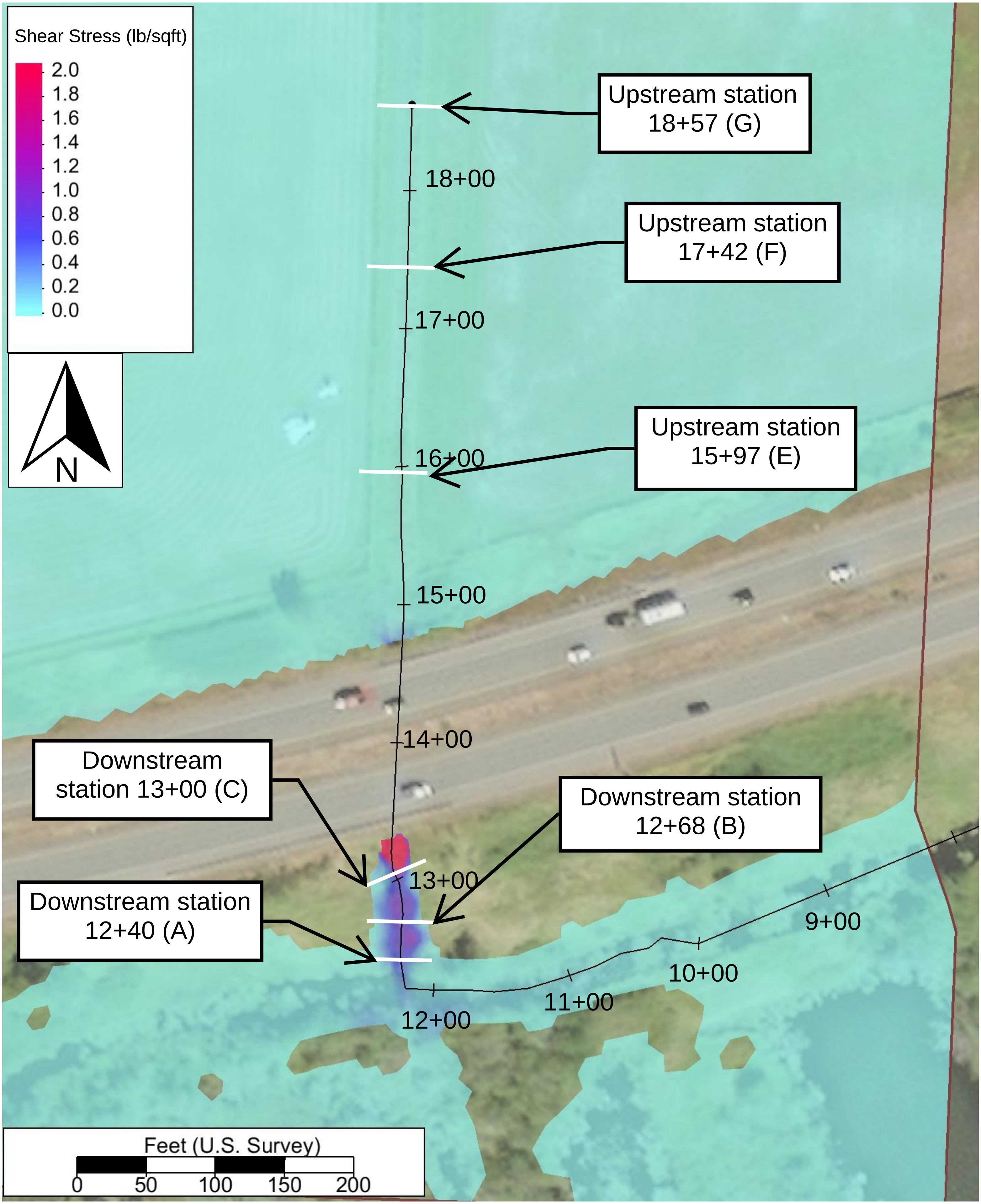


Figure H.8: Existing conditions 100-year Vance, low flow Chehalis shear stress

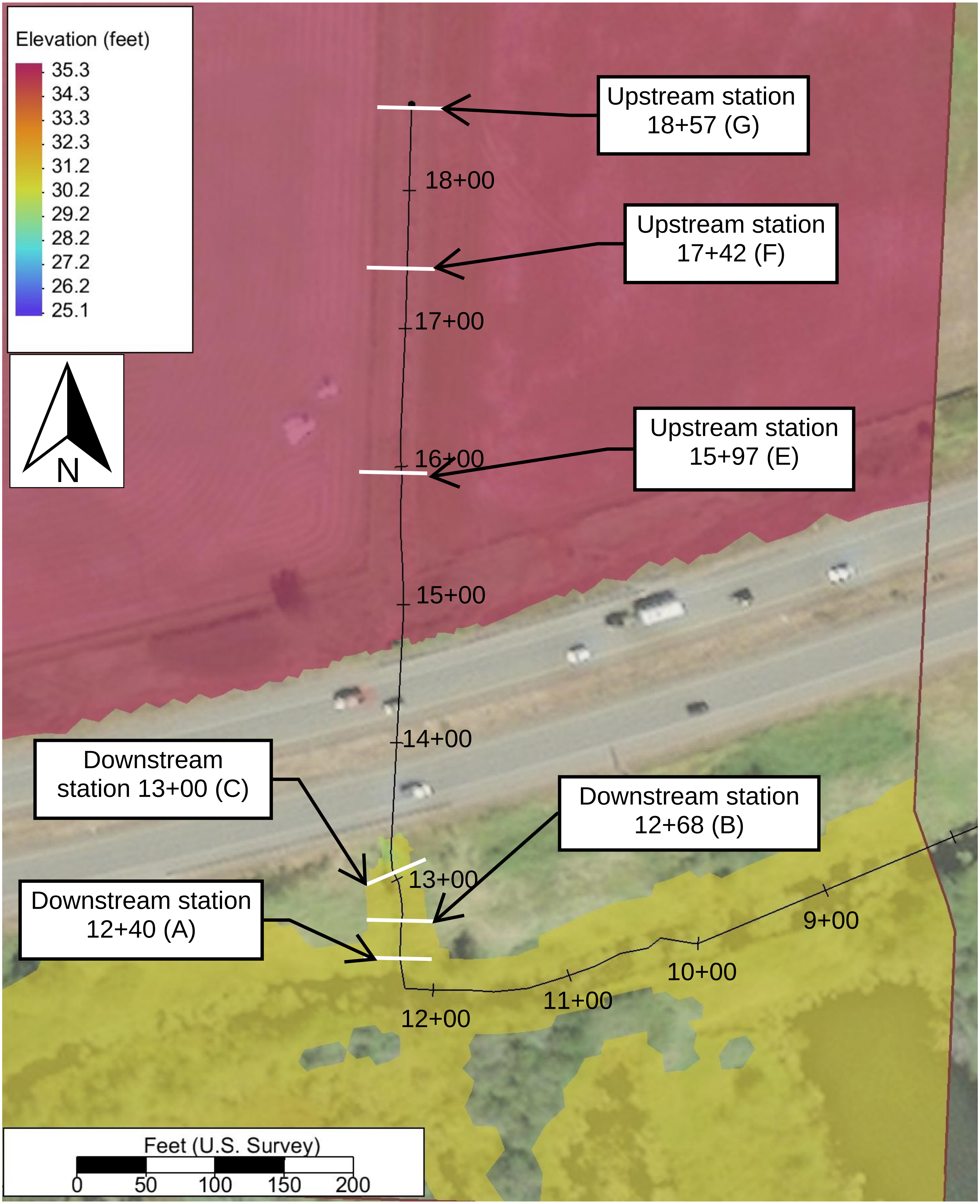


Figure H.9: Existing conditions 500-year Vance, low flow Chehalis water surface elevation

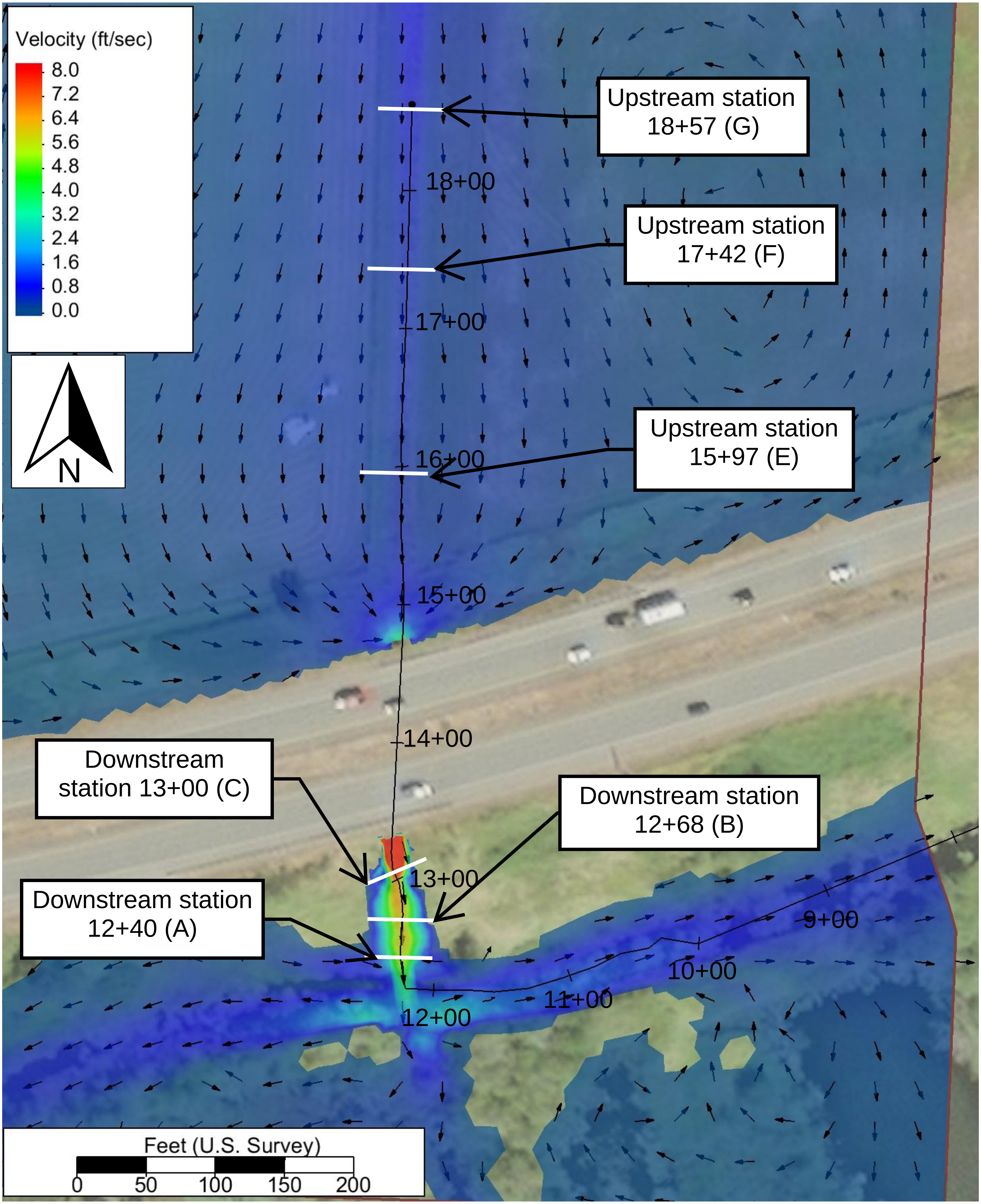


Figure H.10: Existing conditions 500-year Vance, low flow Chehalis velocity

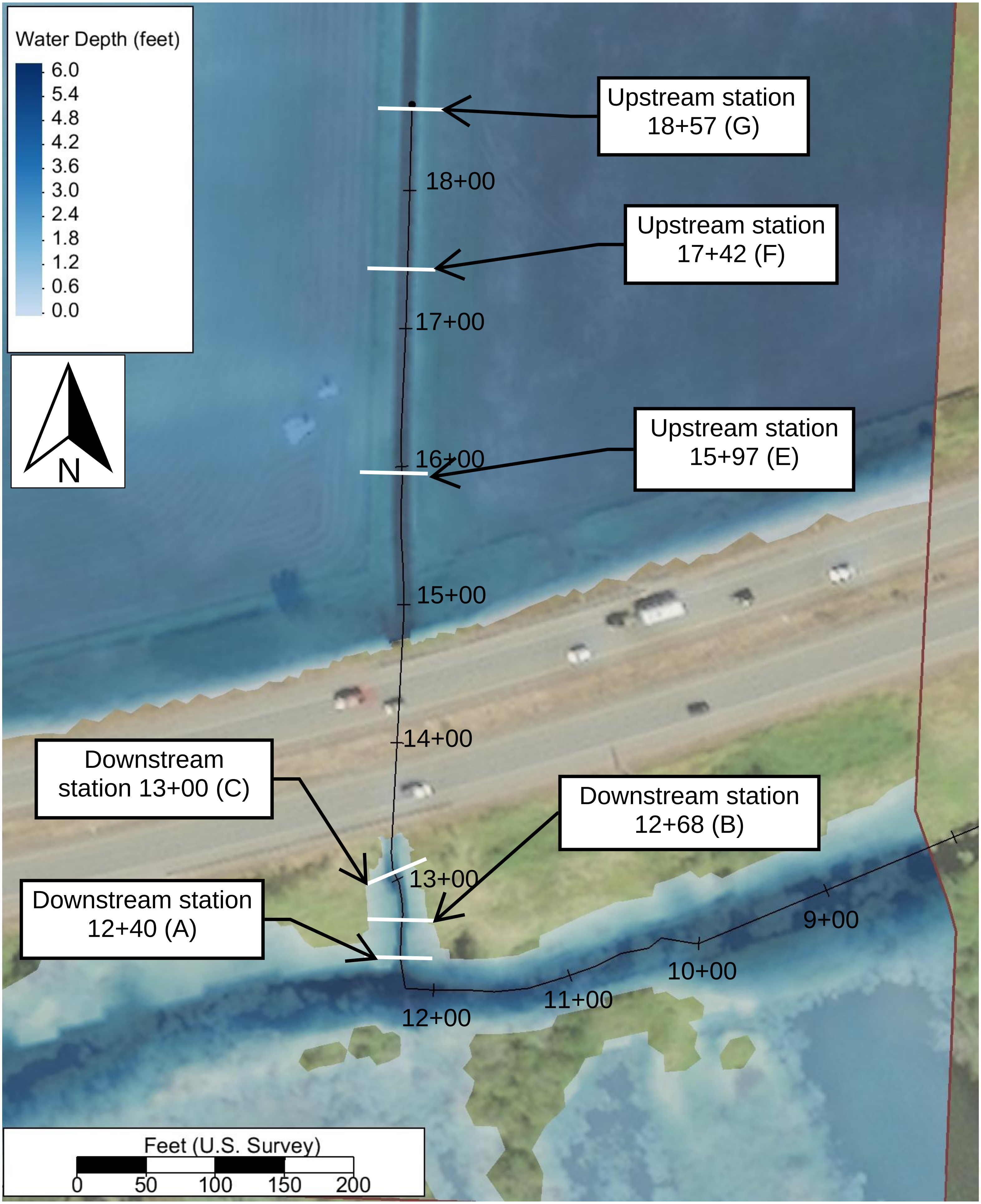


Figure H.11: Existing conditions 500-year Vance, low flow Chehalis water depth

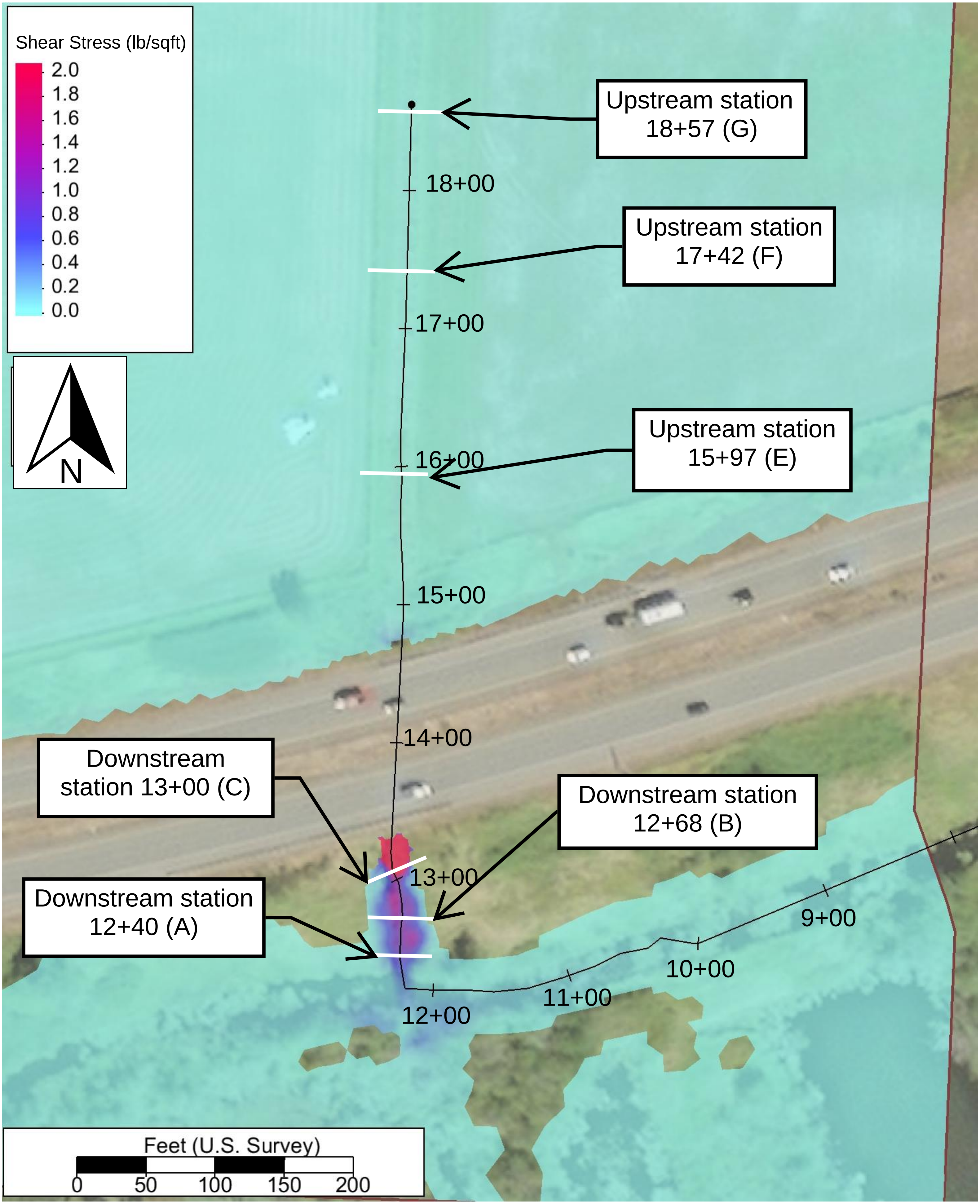


Figure H.12: Existing conditions 500-year Vance, low flow Chehalis shear stress

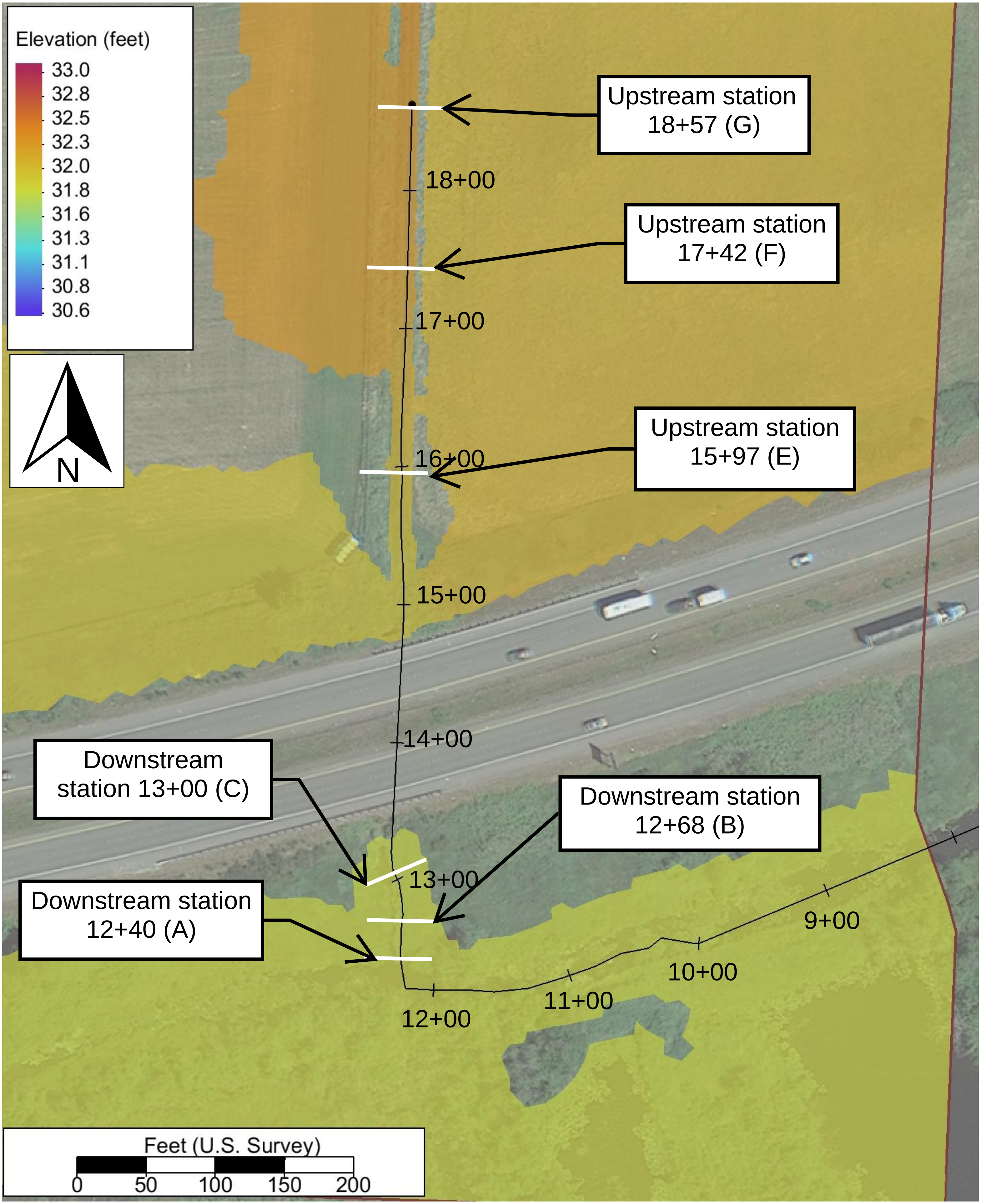


Figure H.13: Existing conditions 2-year Vance, 2-year Chehalis water surface elevation

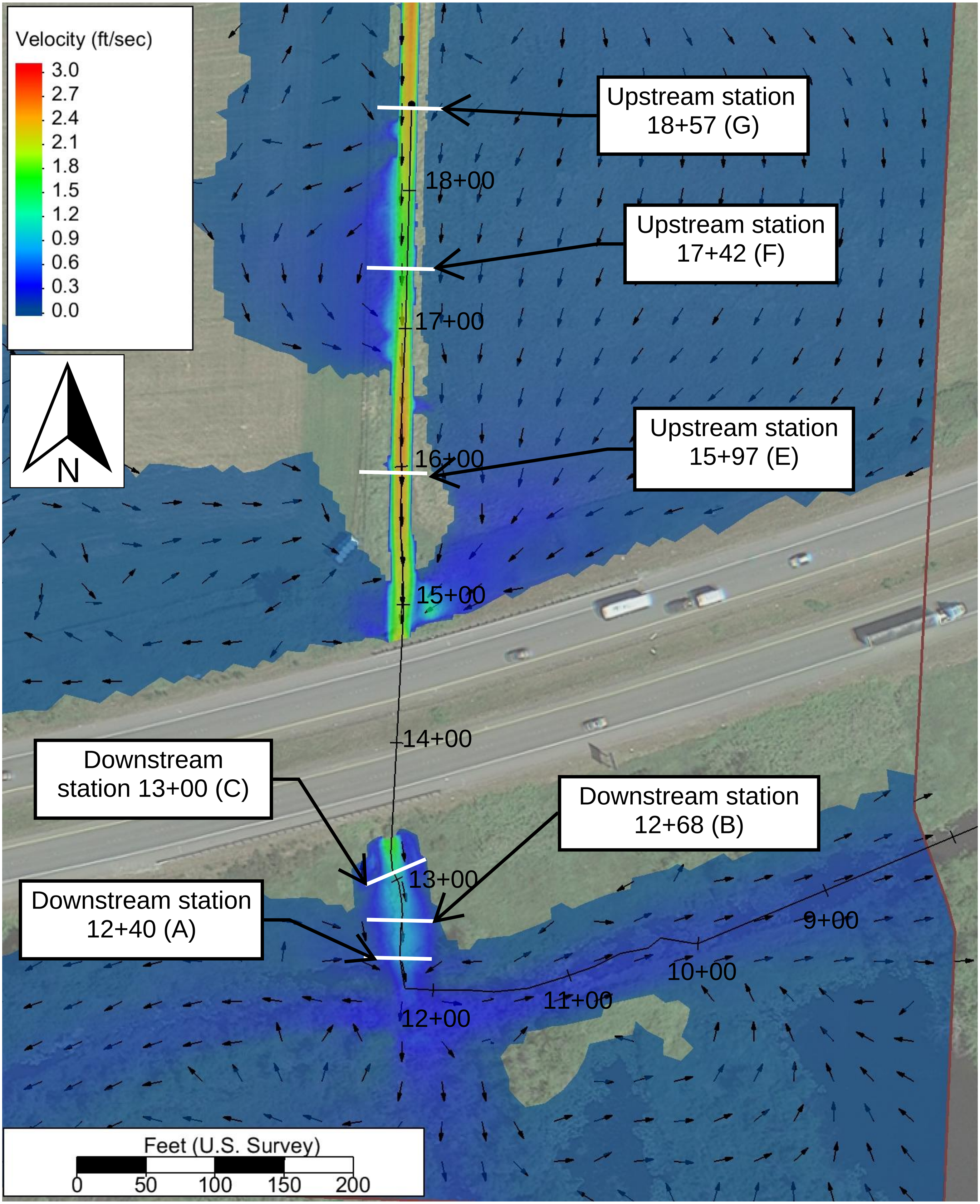


Figure H.14: Existing conditions 2-year Vance, 2-year Chehalis velocity

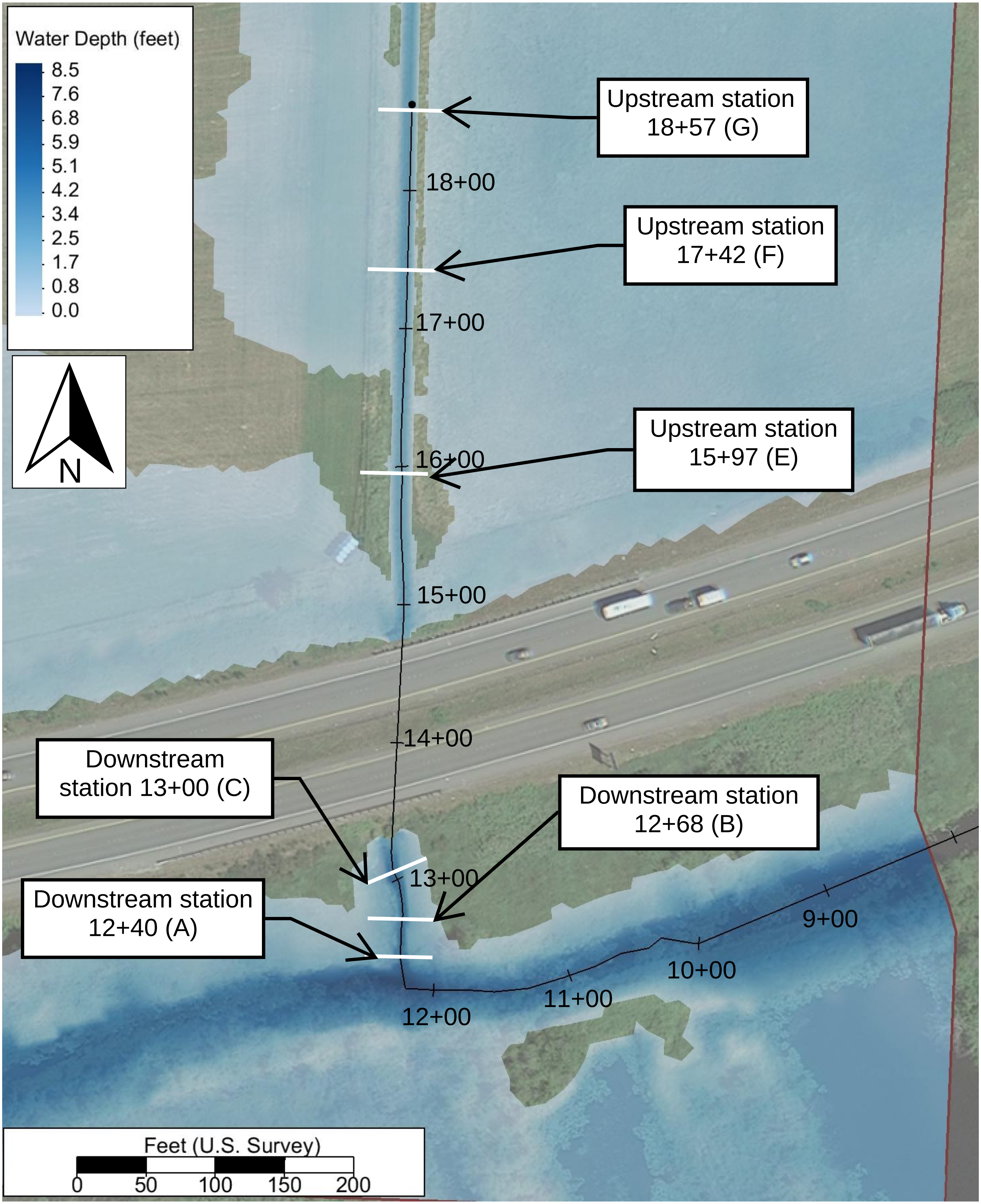


Figure H.15: Existing conditions 2-year Vance, 2-year Chehalis water depth

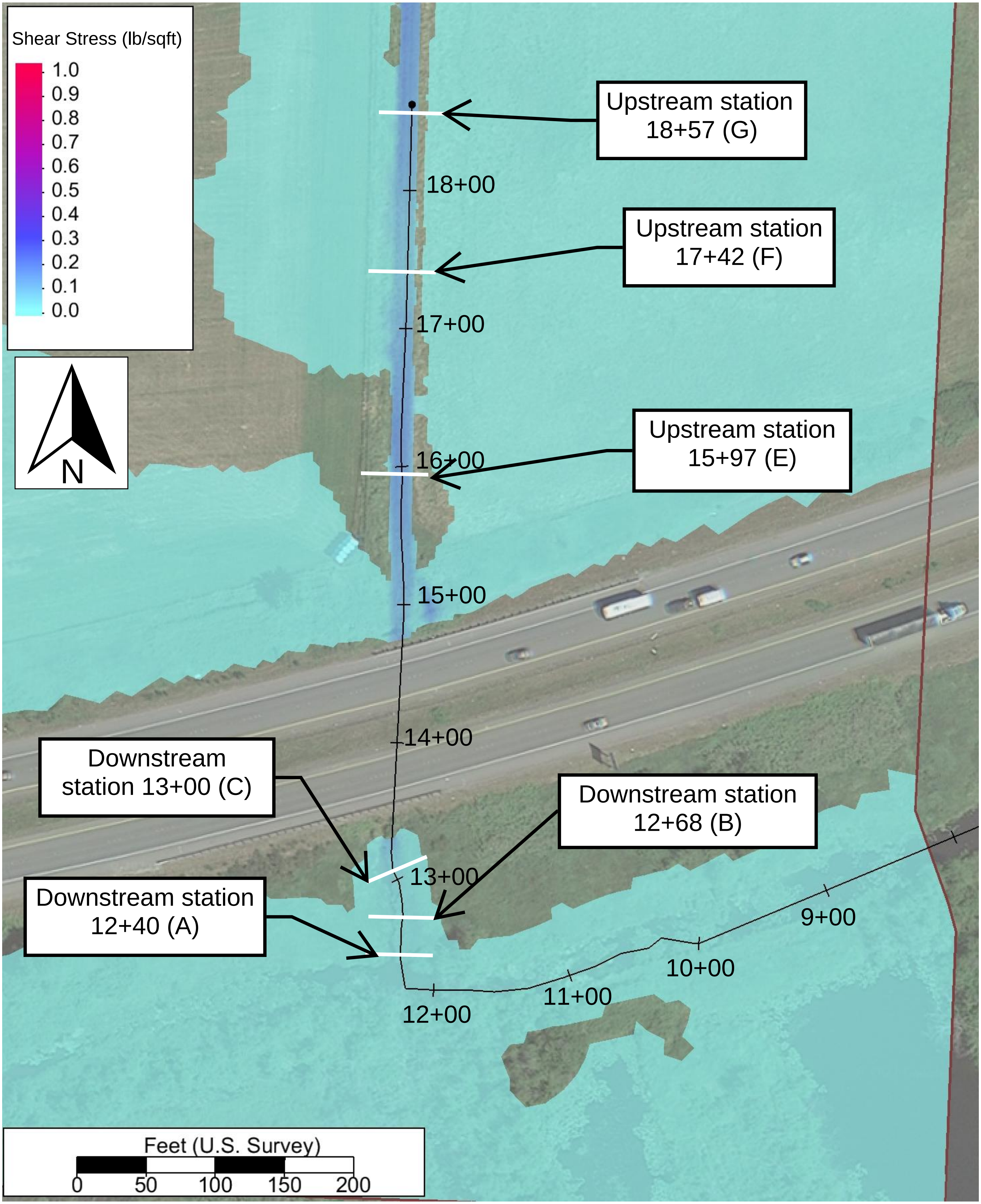


Figure H.16: Existing conditions 2-year Vance, 2-year Chehalis shear stress

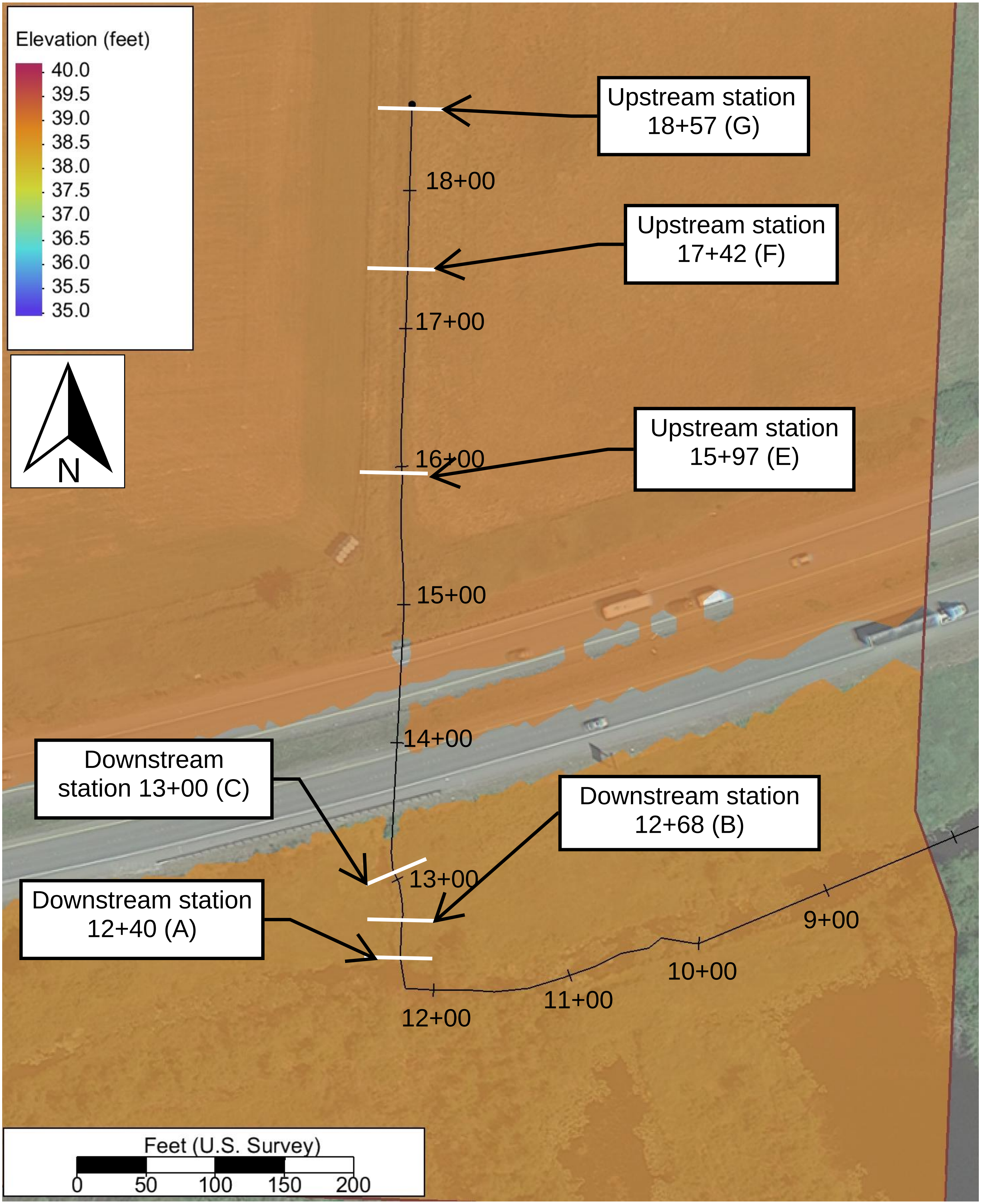


Figure H.17: Existing conditions 2-year Vance, 100-year Chehalis water surface elevation

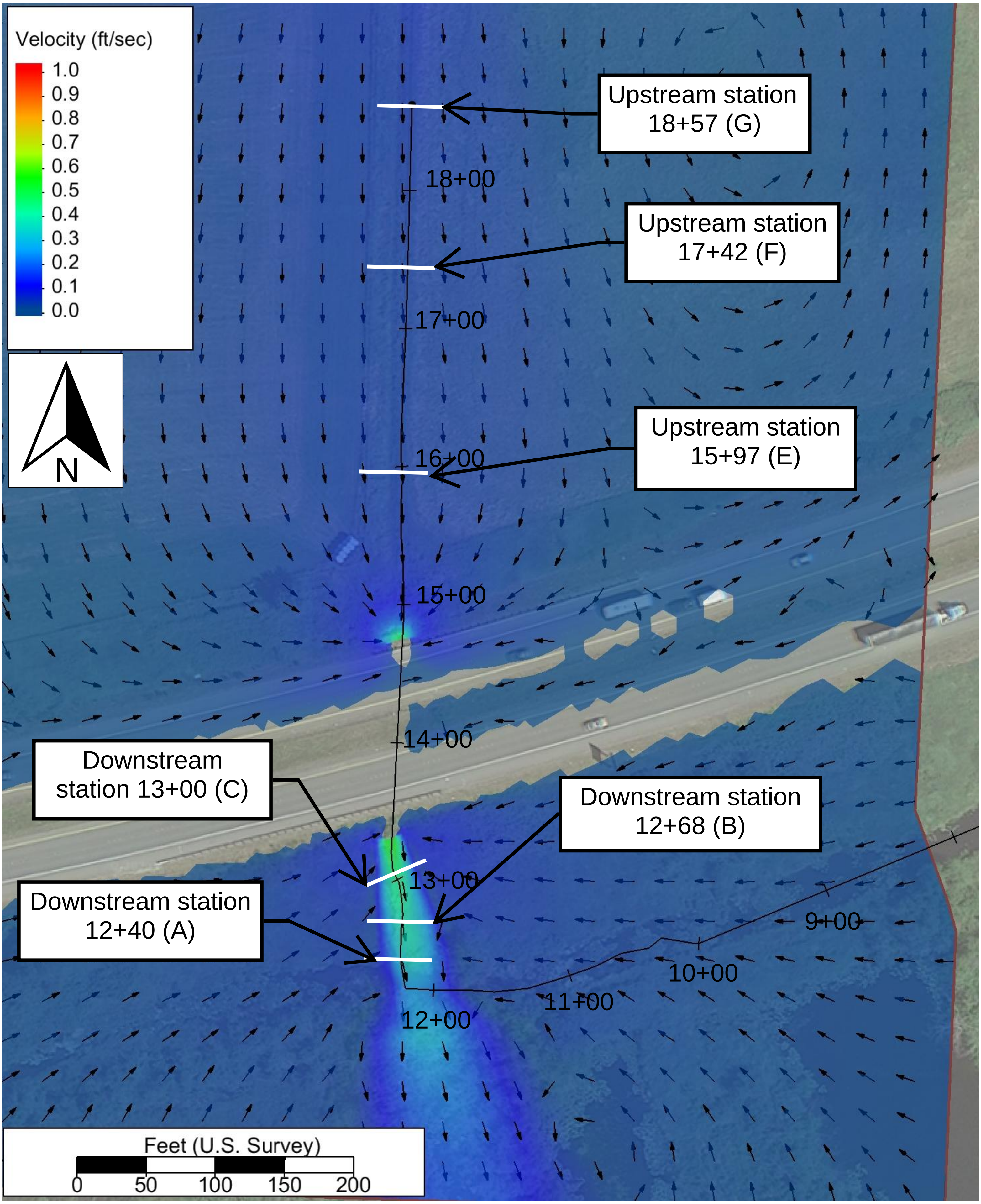


Figure H.18: Existing conditions 2-year Vance, 100-year Chehalis velocity

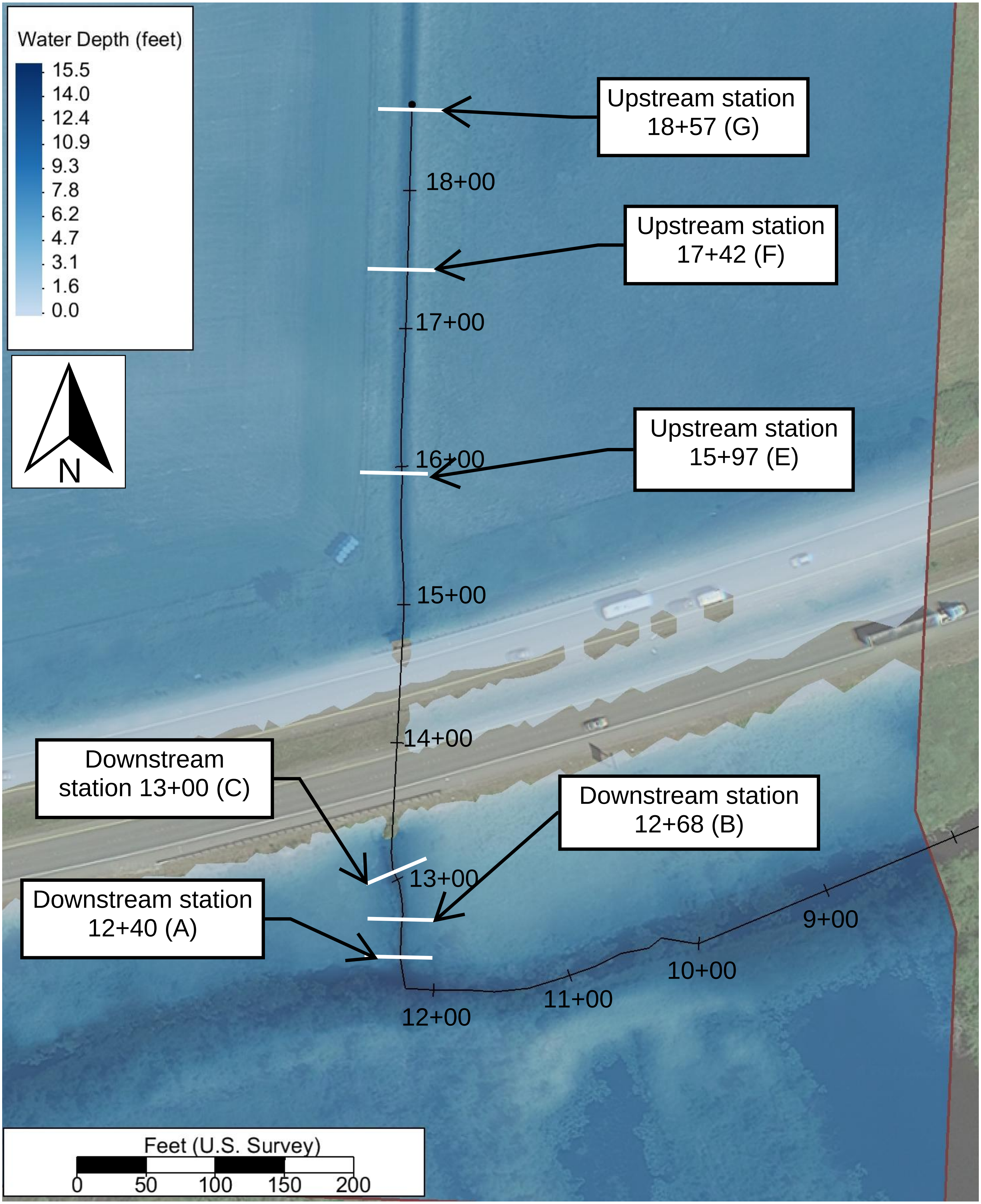


Figure H.19: Existing conditions 2-year Vance, 100-year Chehalis water depth

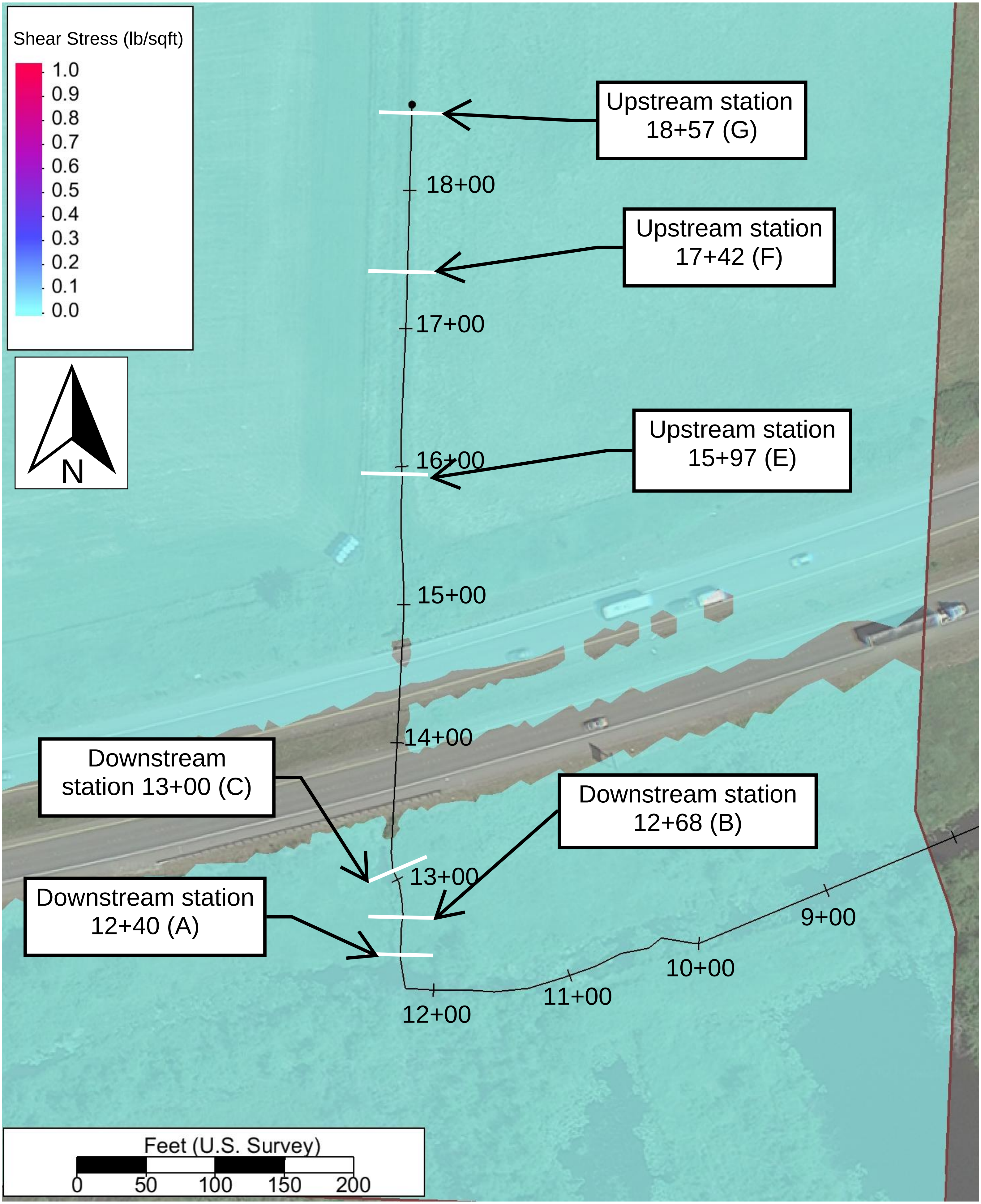


Figure H.20: Existing conditions 2-year Vance, 100-year Chehalis shear stress

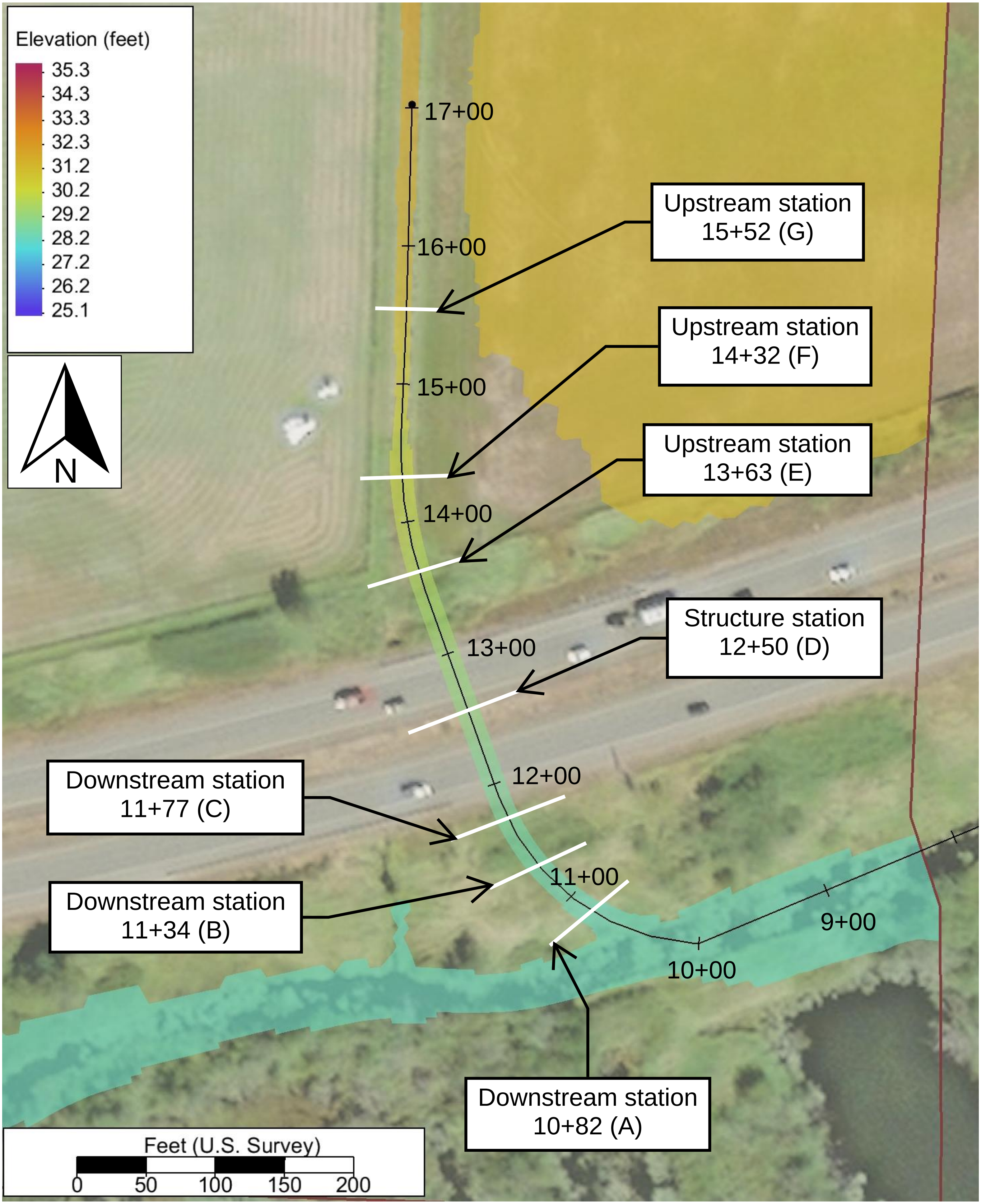


Figure H.21: Proposed conditions 2-year Vance, low flow Chehalis water surface elevation

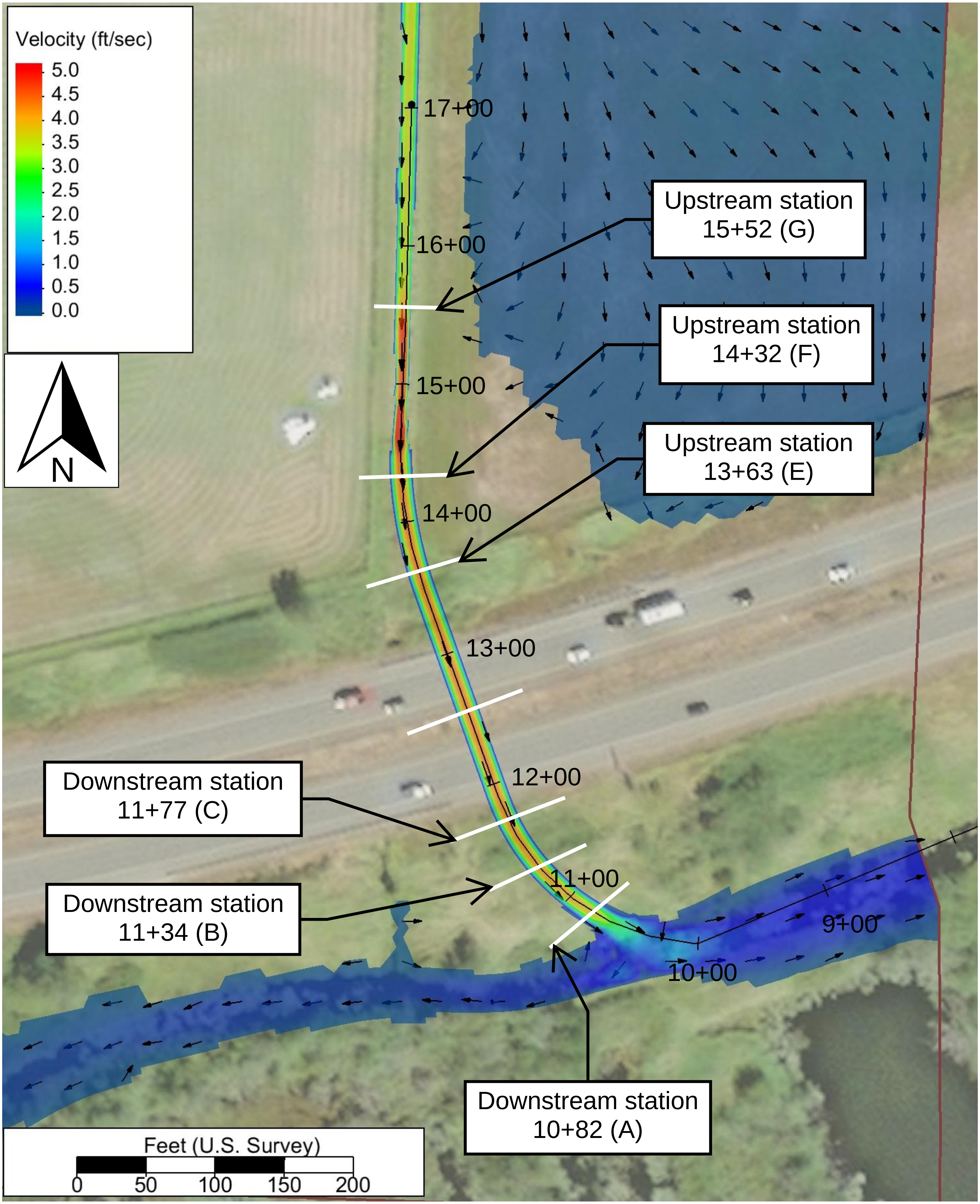


Figure H.22: Proposed conditions 2-year Vance, low flow Chehalis velocity

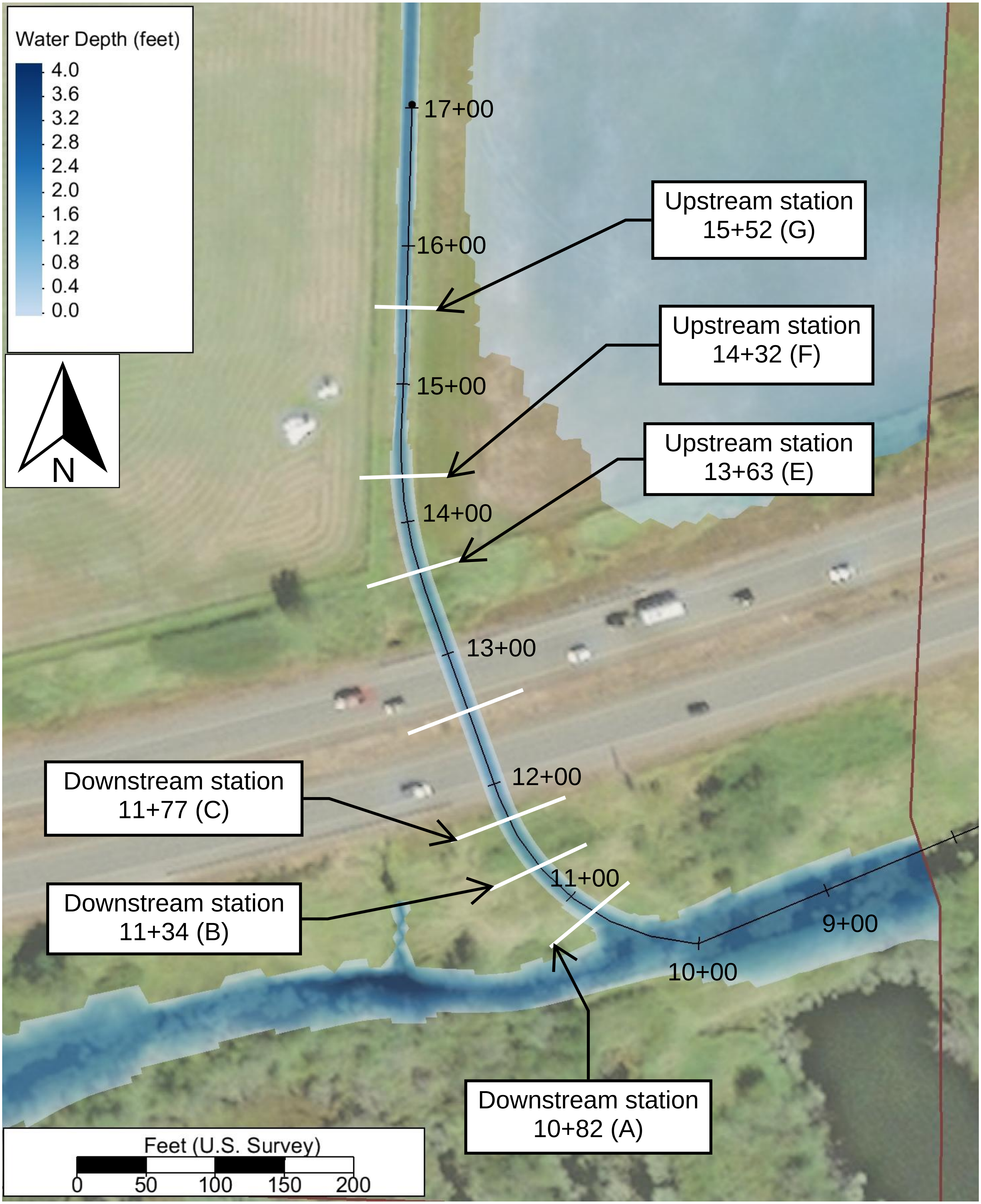


Figure H.23: Proposed conditions 2-year Vance, low flow Chehalis water depth

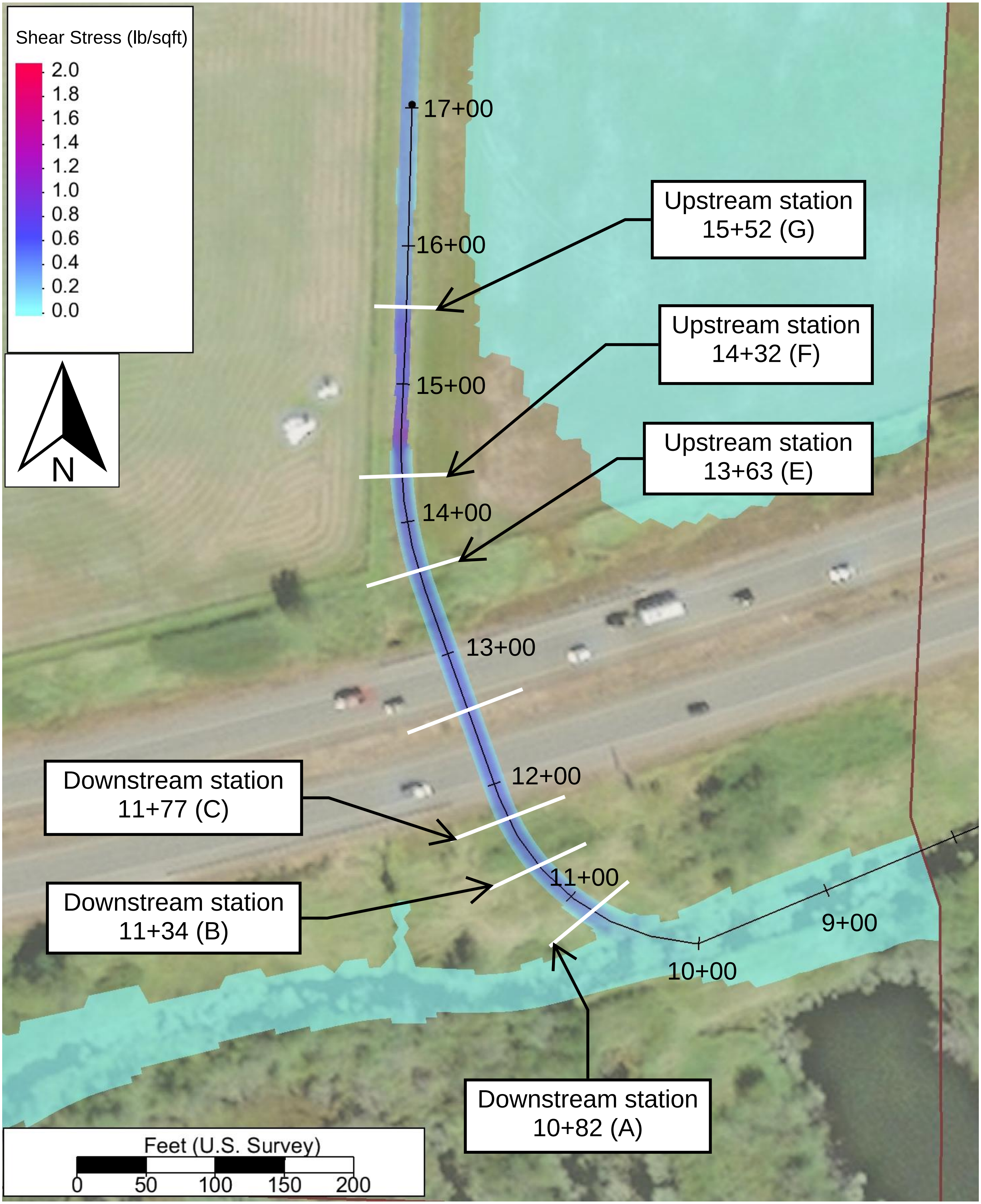


Figure H.24: Proposed conditions 2-year Vance, low flow Chehalis shear stress

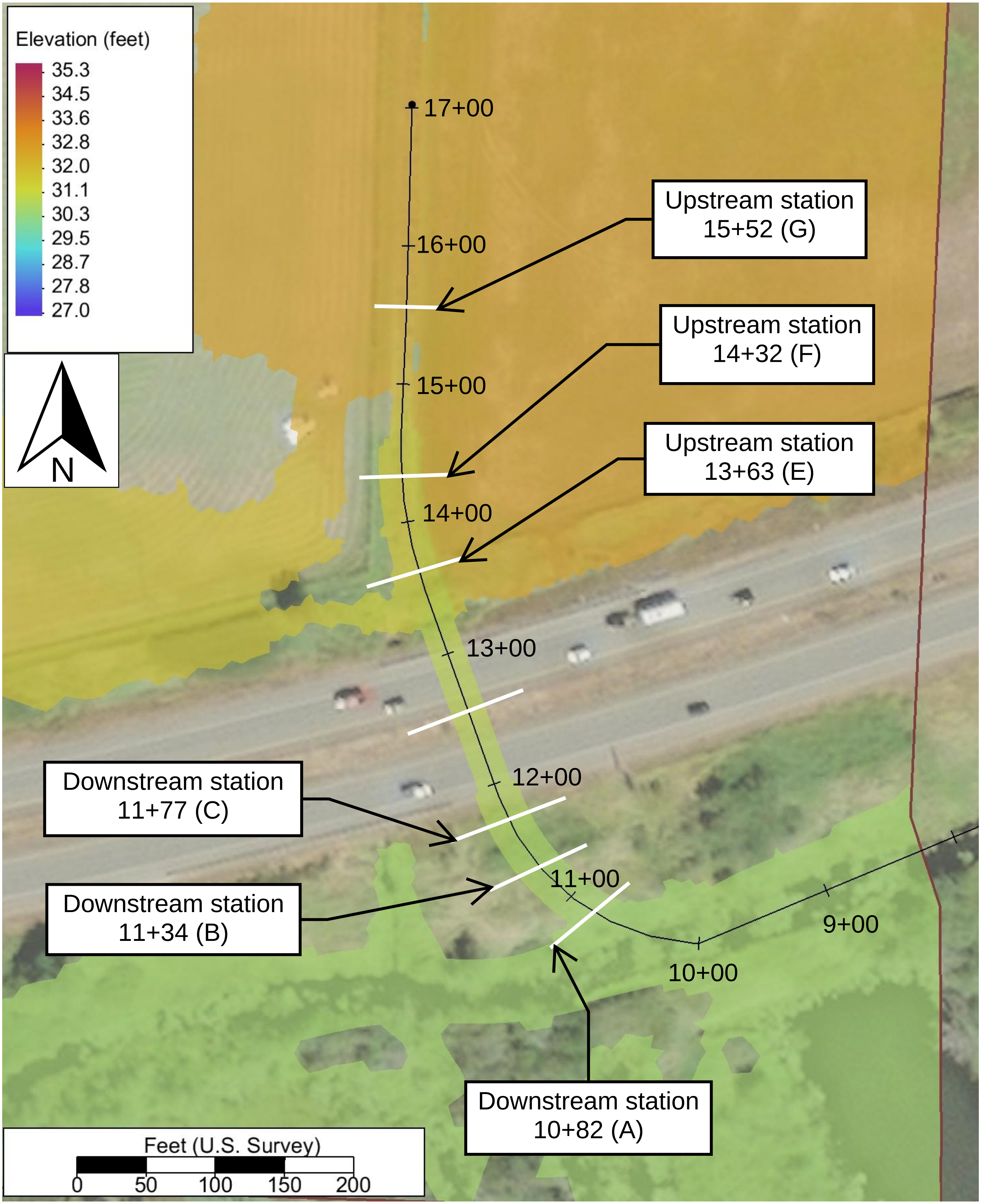


Figure H.25: Proposed conditions 100-year Vance, low flow Chehalis water surface elevation

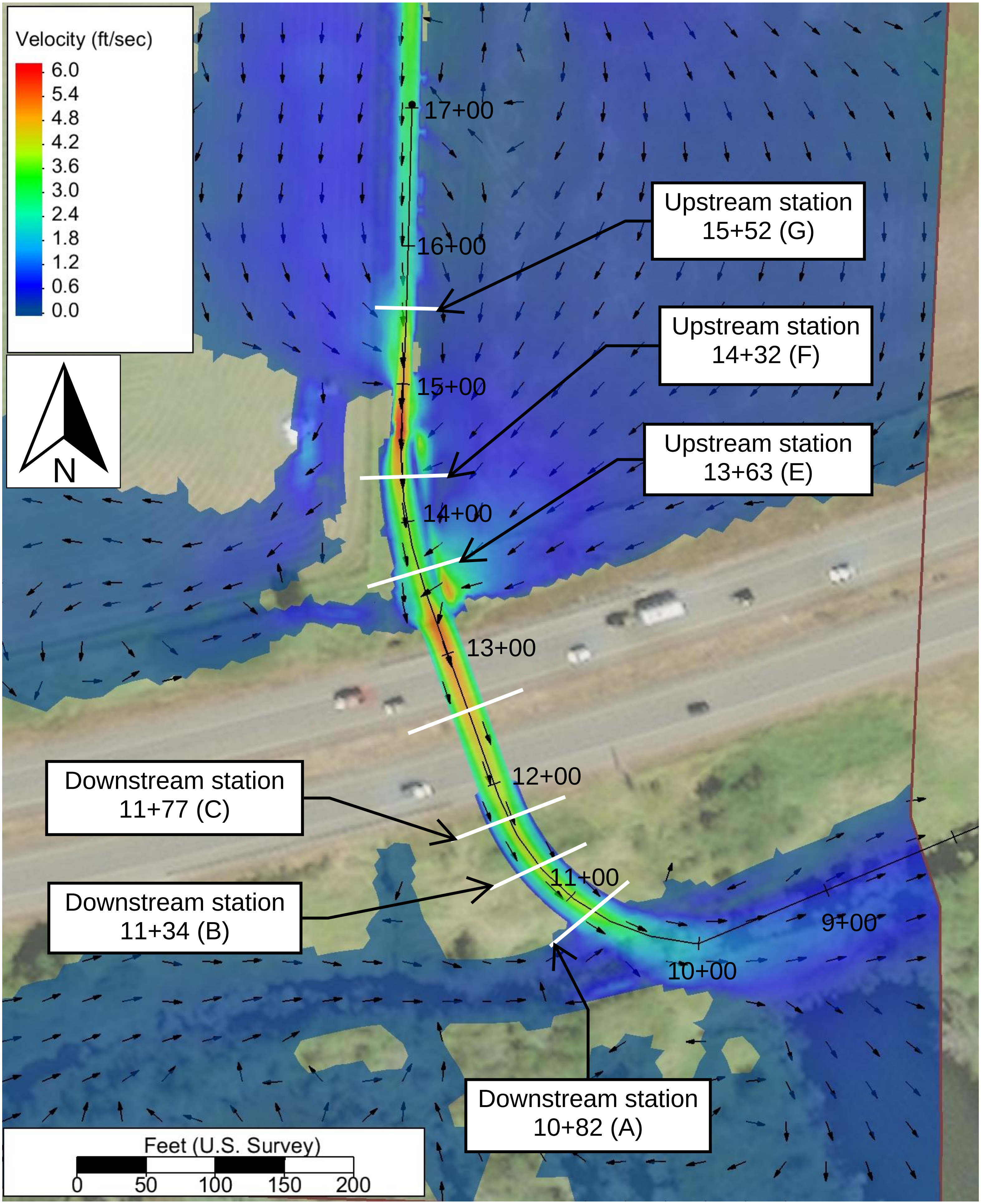


Figure H.26: Proposed conditions 100-year Vance, low flow Chehalis velocity

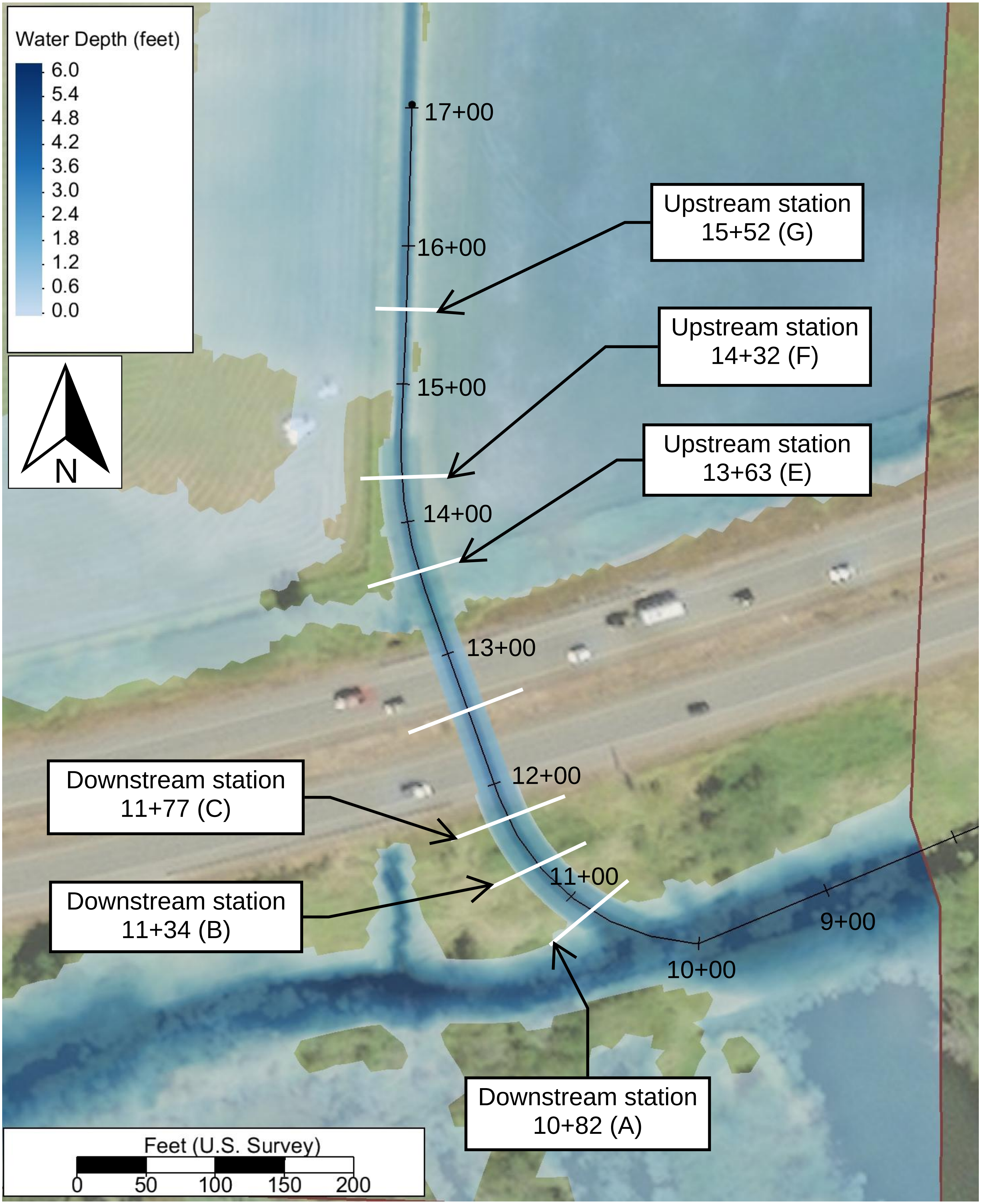


Figure H.27: Proposed conditions 100-year Vance, low flow Chehalis water depth

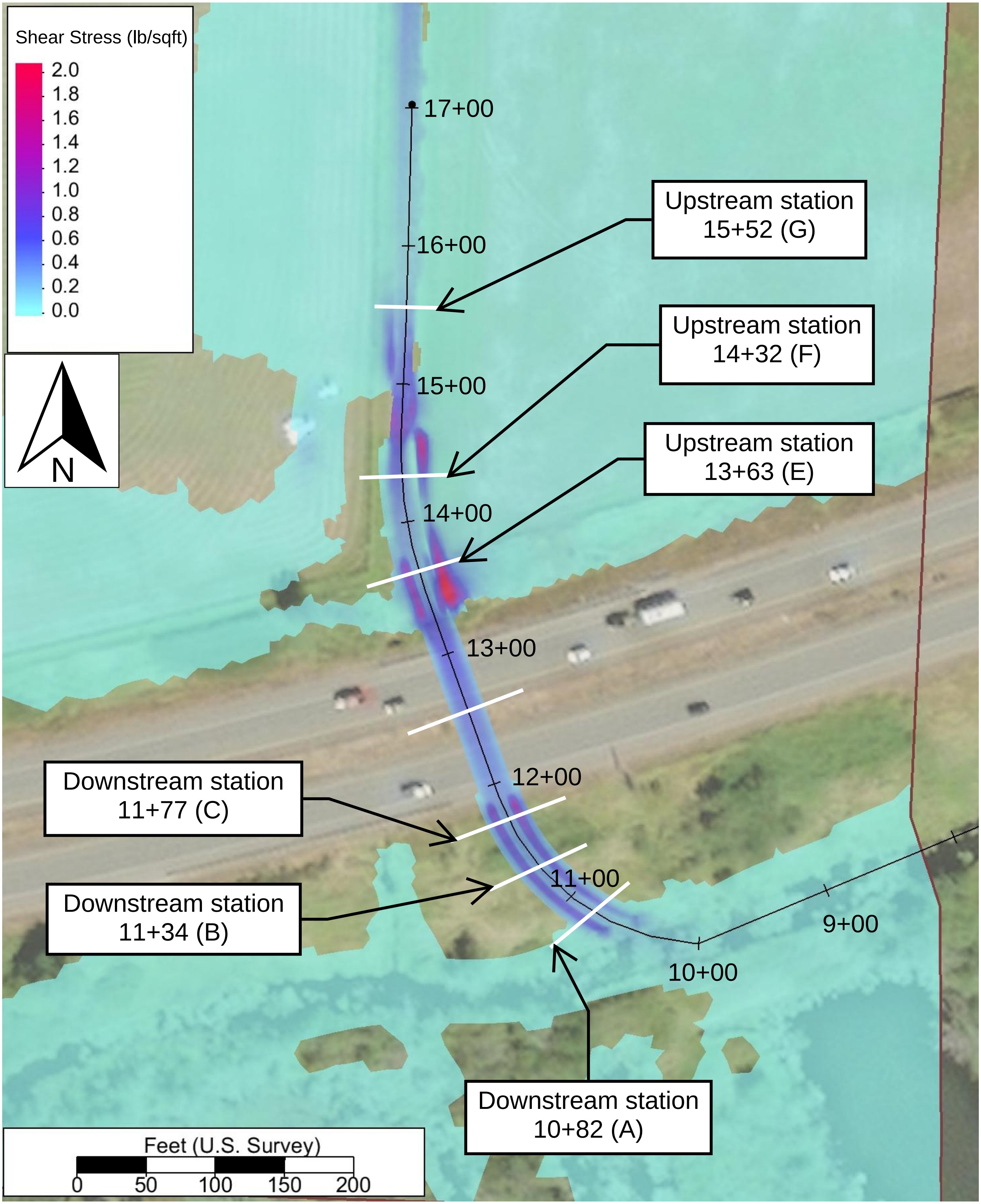


Figure H.28: Proposed conditions 100-year Vance, low flow Chehalis shear stress

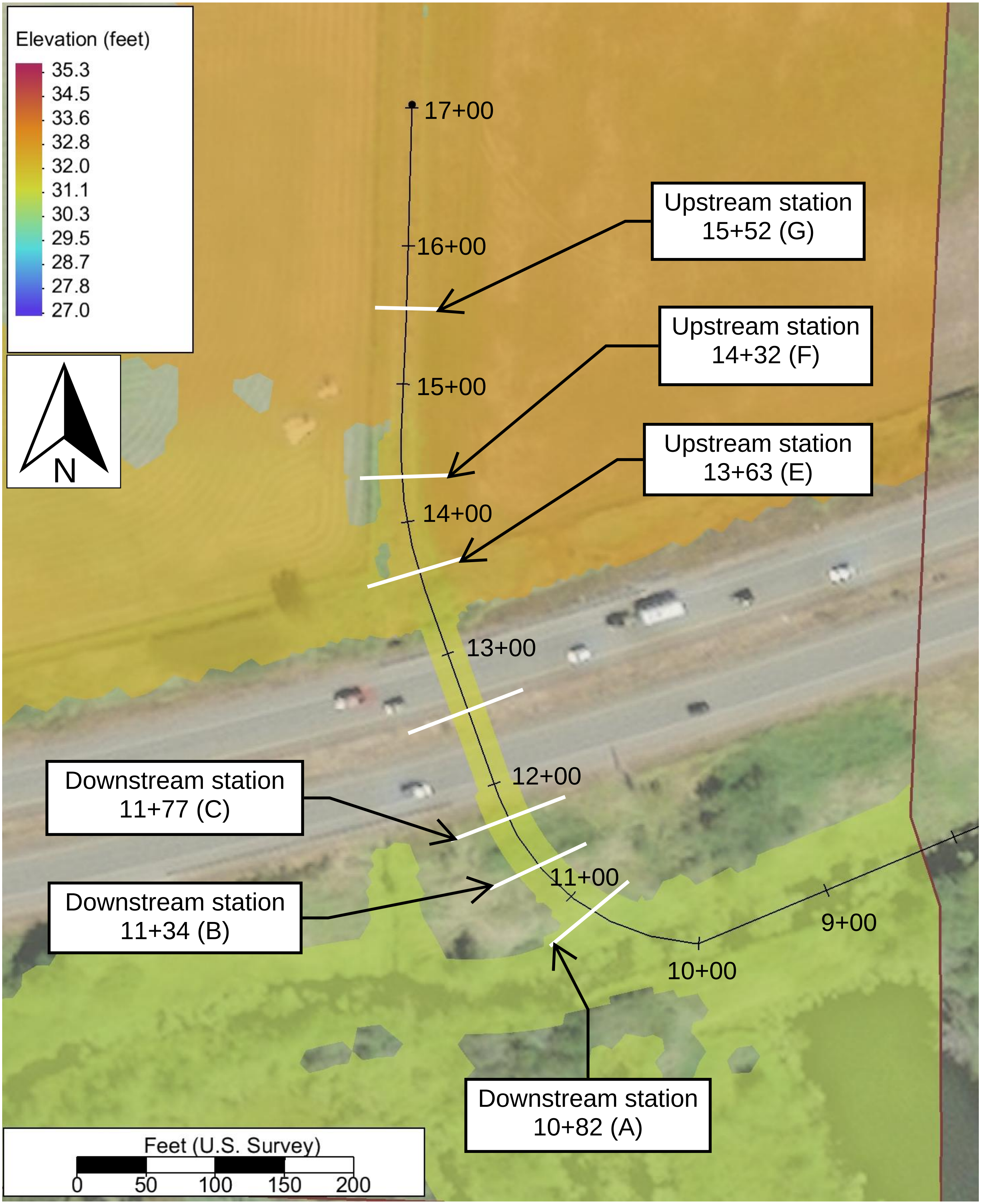


Figure H.29: Proposed conditions 500-year Vance, low flow Chehalis water surface elevation

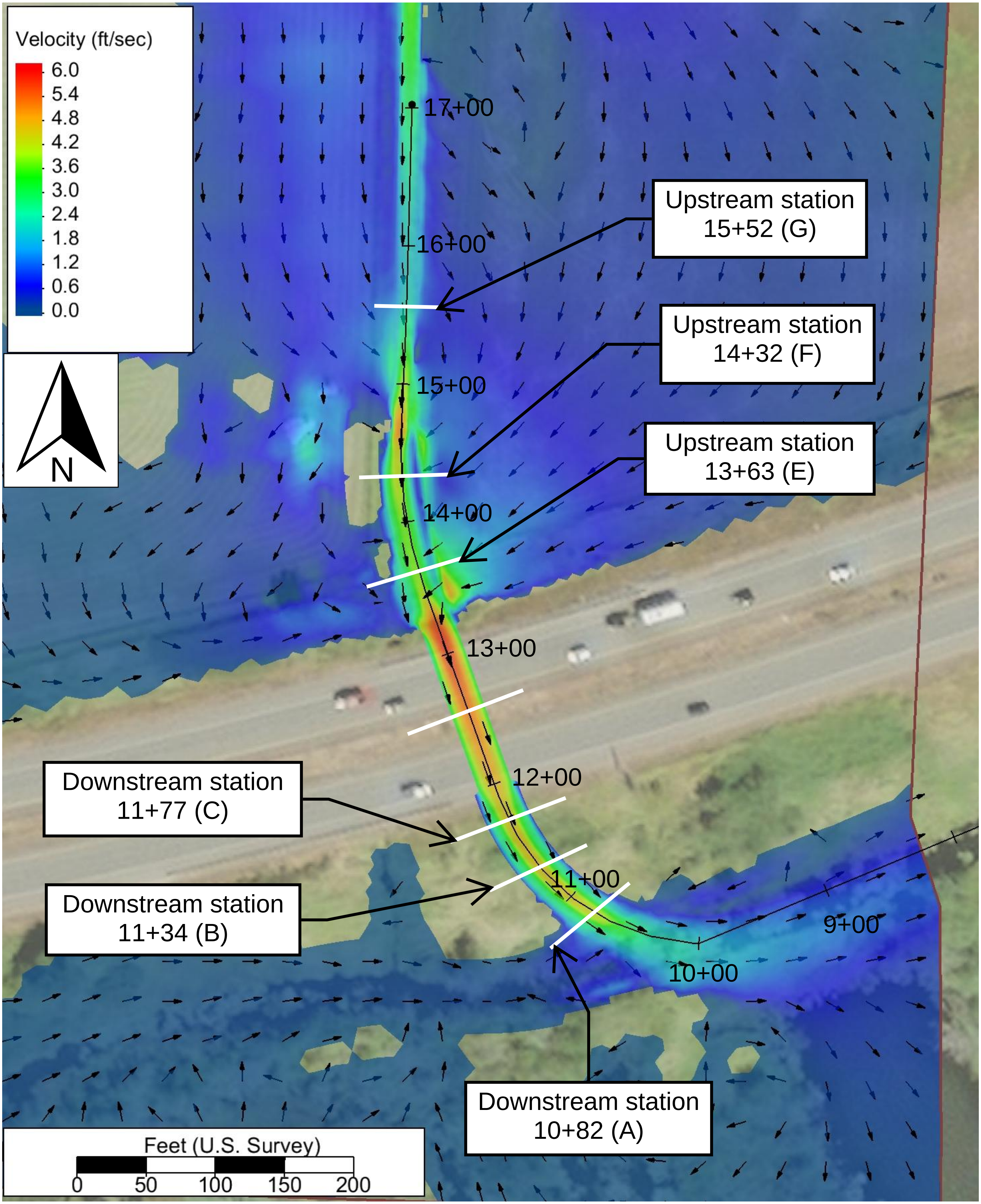


Figure H.30: Proposed conditions 500-year Vance, low flow Chehalis velocity

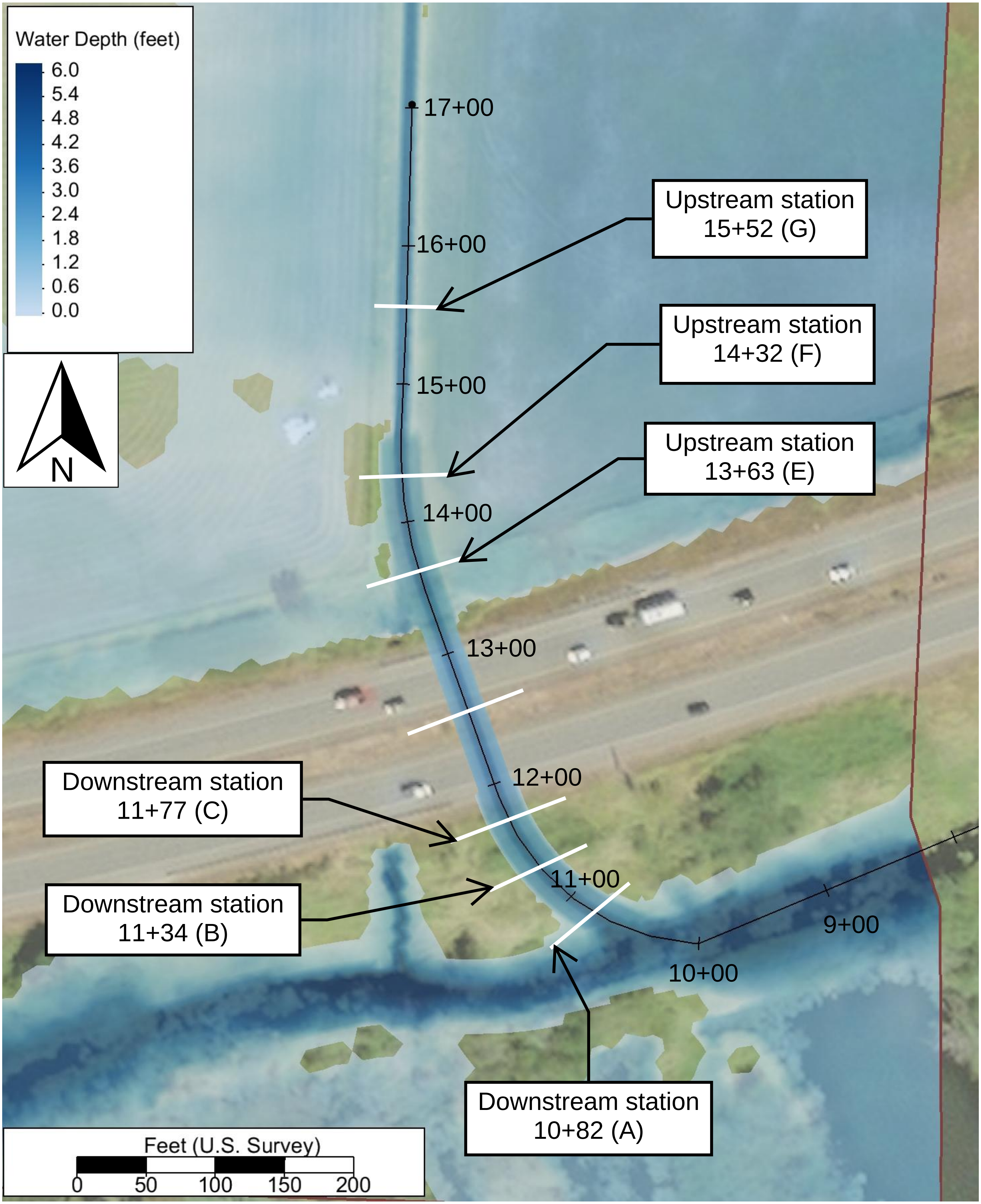


Figure H.31: Proposed conditions 500-year Vance, low flow Chehalis water depth

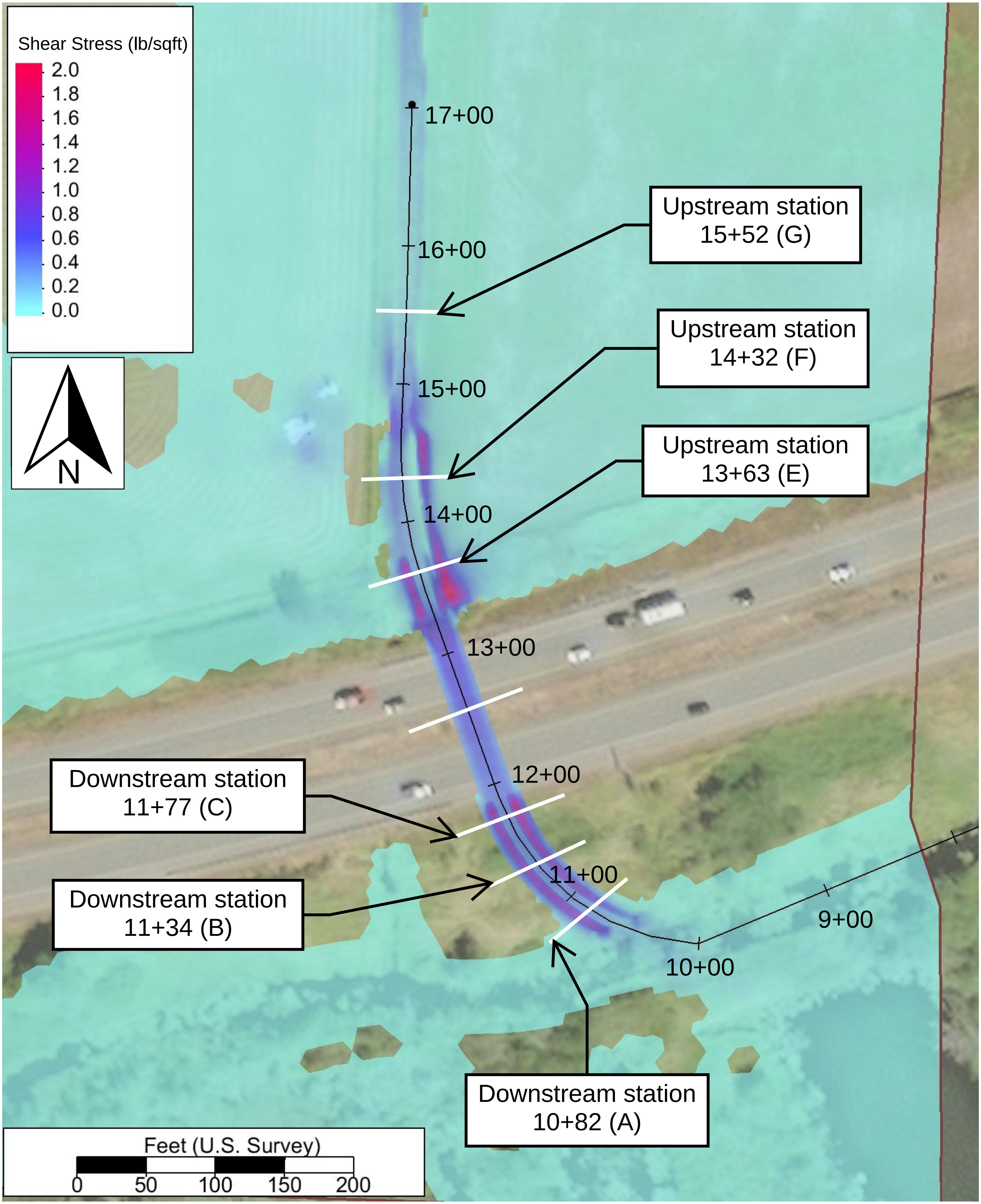


Figure H.32: Proposed conditions 500-year Vance, low flow Chehalis shear stress

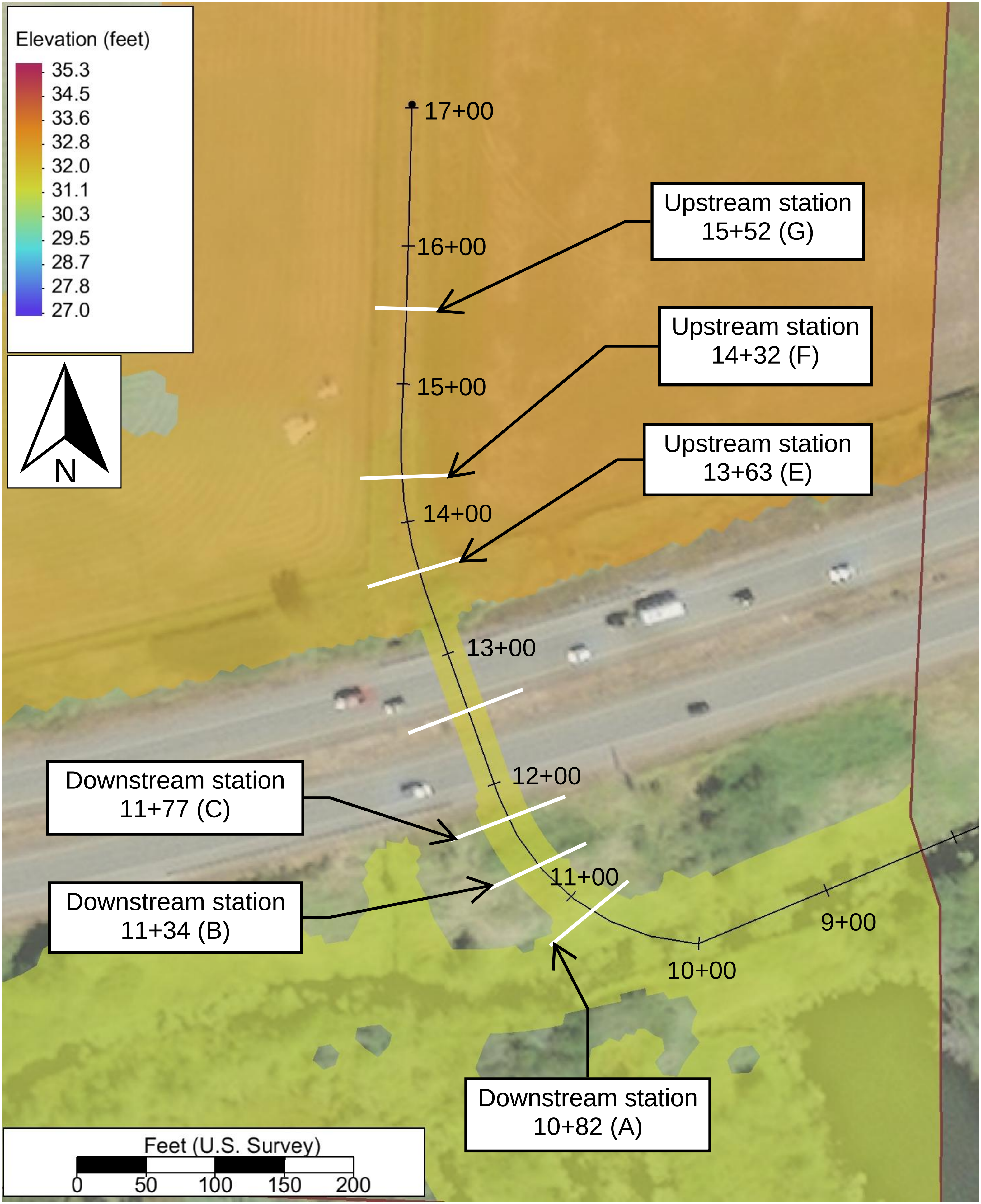


Figure H.33: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis water surface elevation

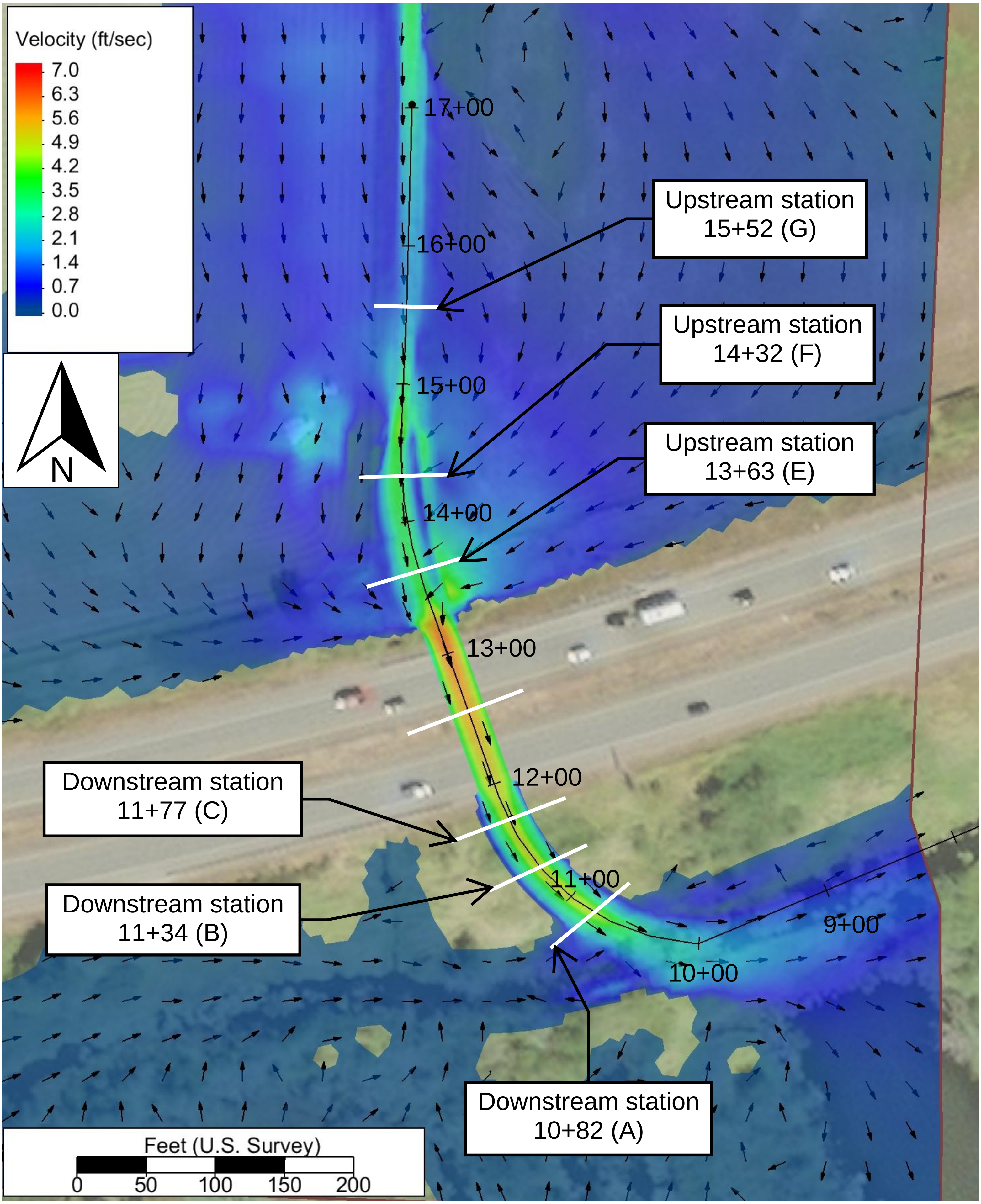


Figure H.34: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis velocity

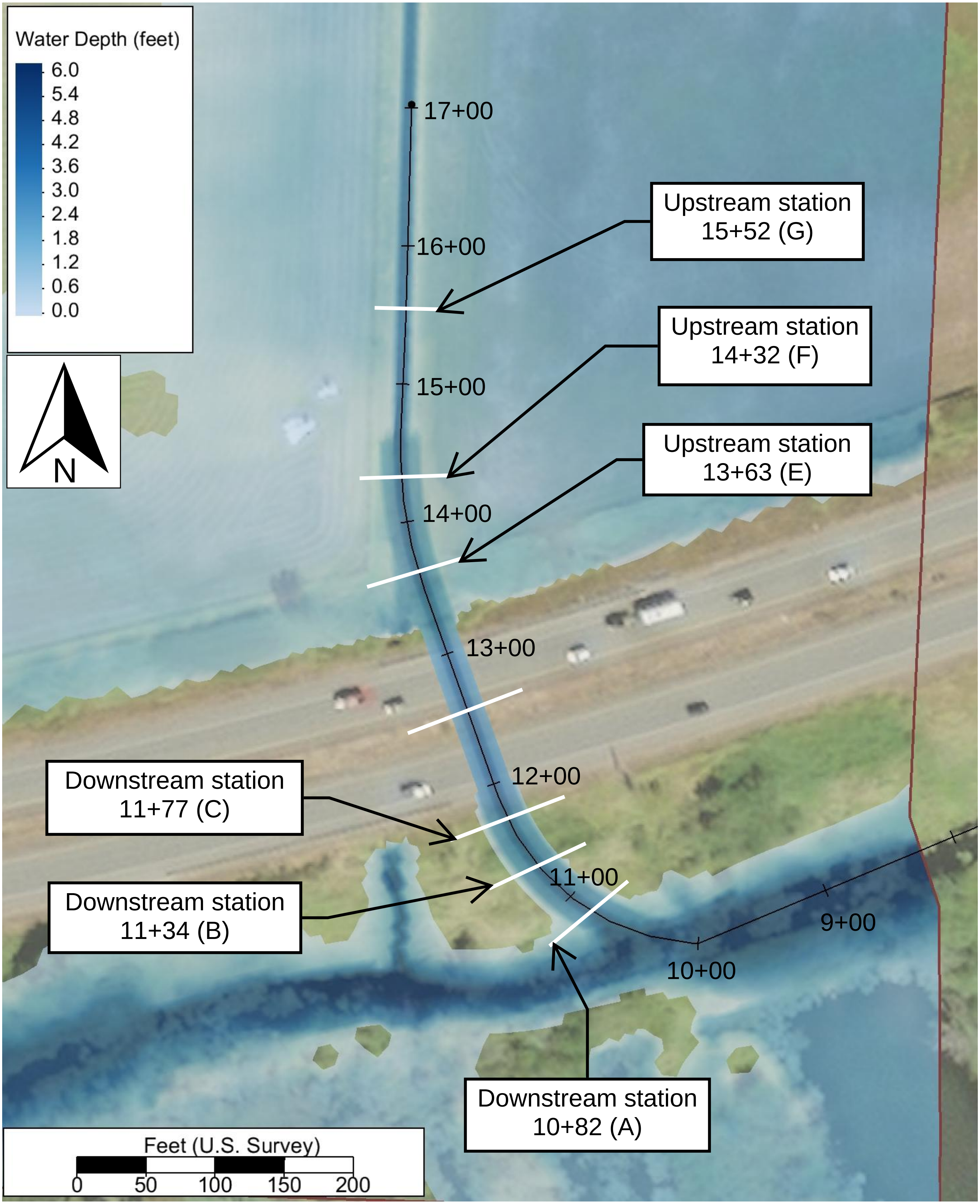


Figure H.35: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis water depth

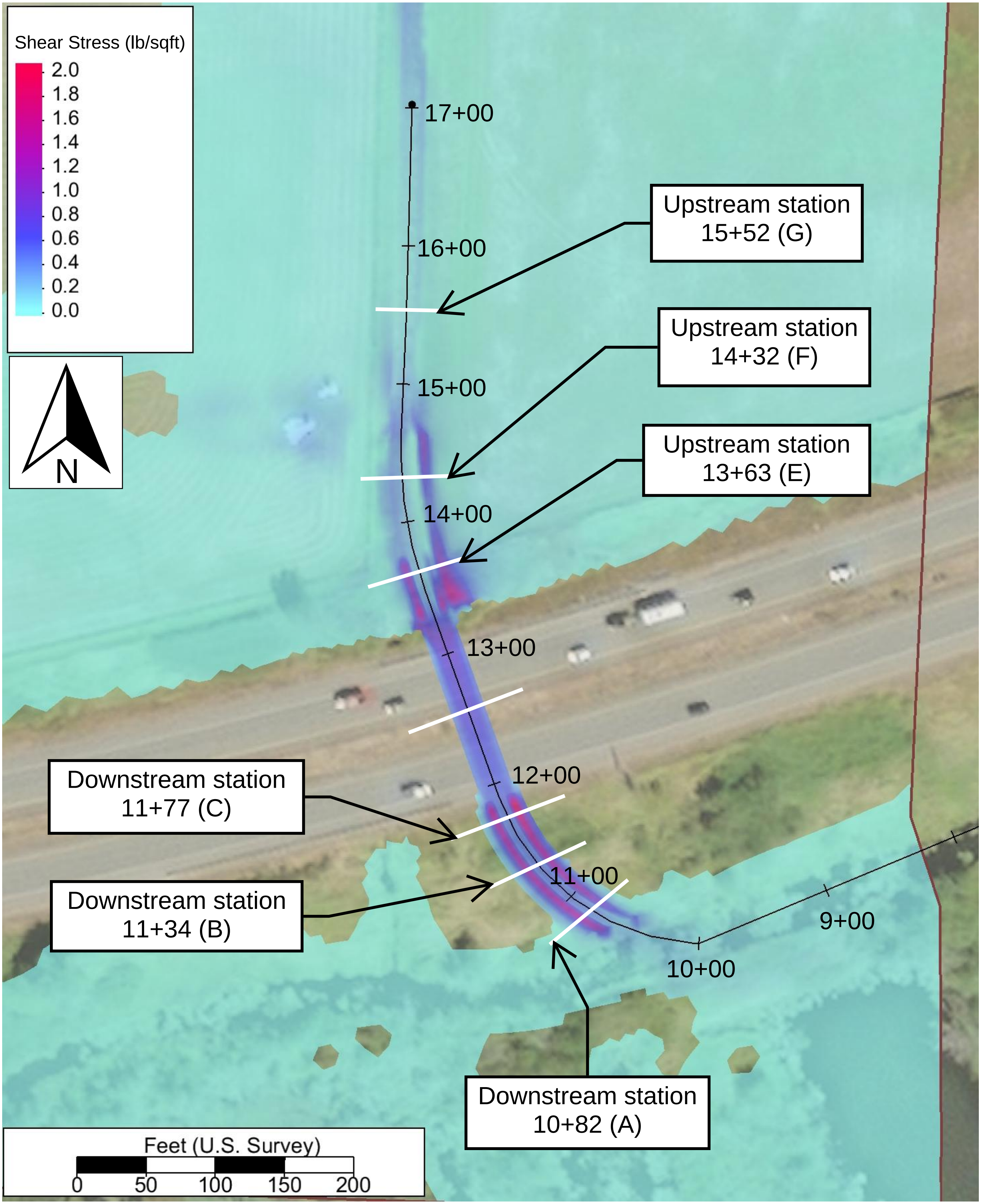


Figure H.36: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis shear stress

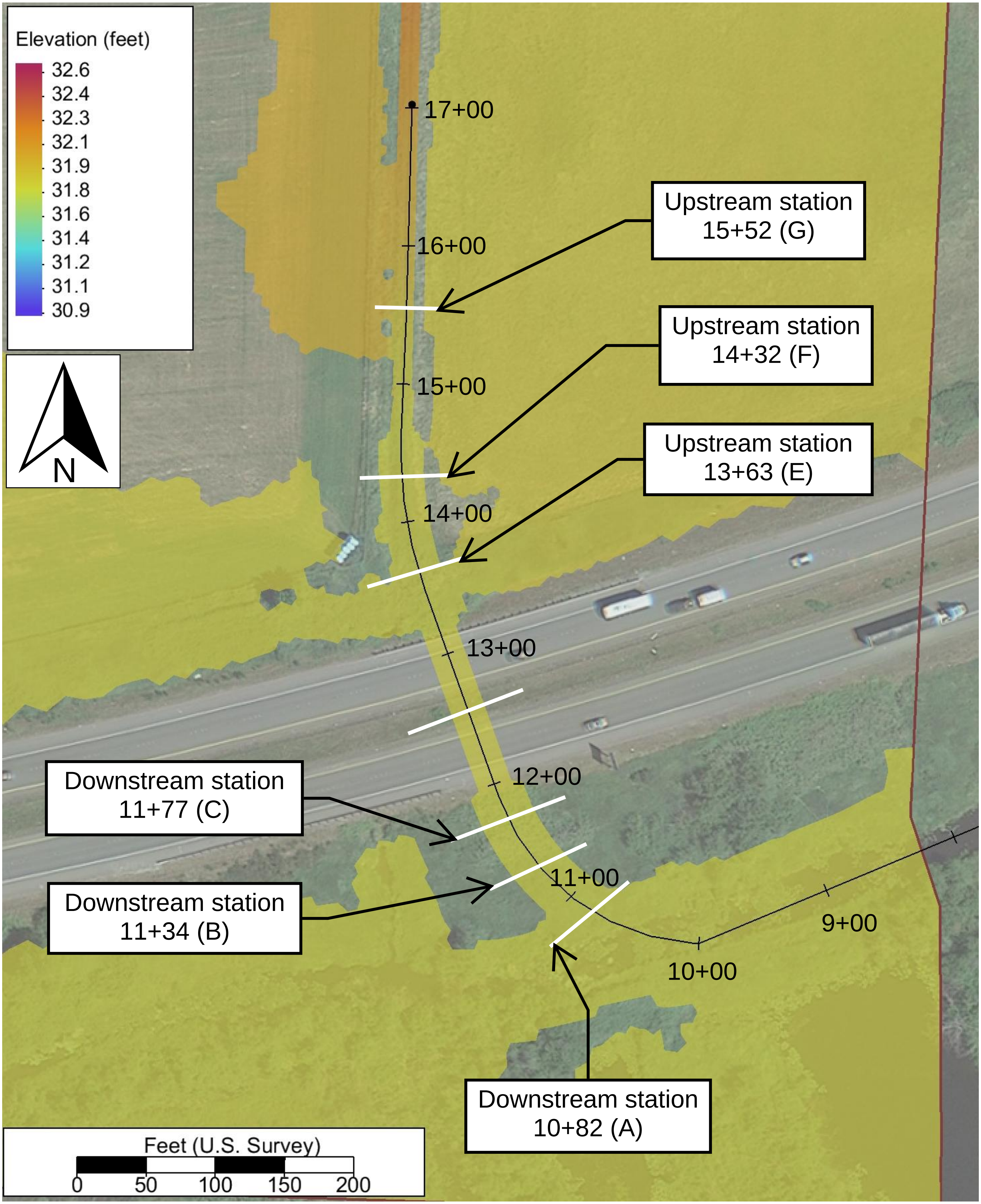


Figure H.37: Proposed conditions 2-year Vance, 2-year Chehalis water surface elevation

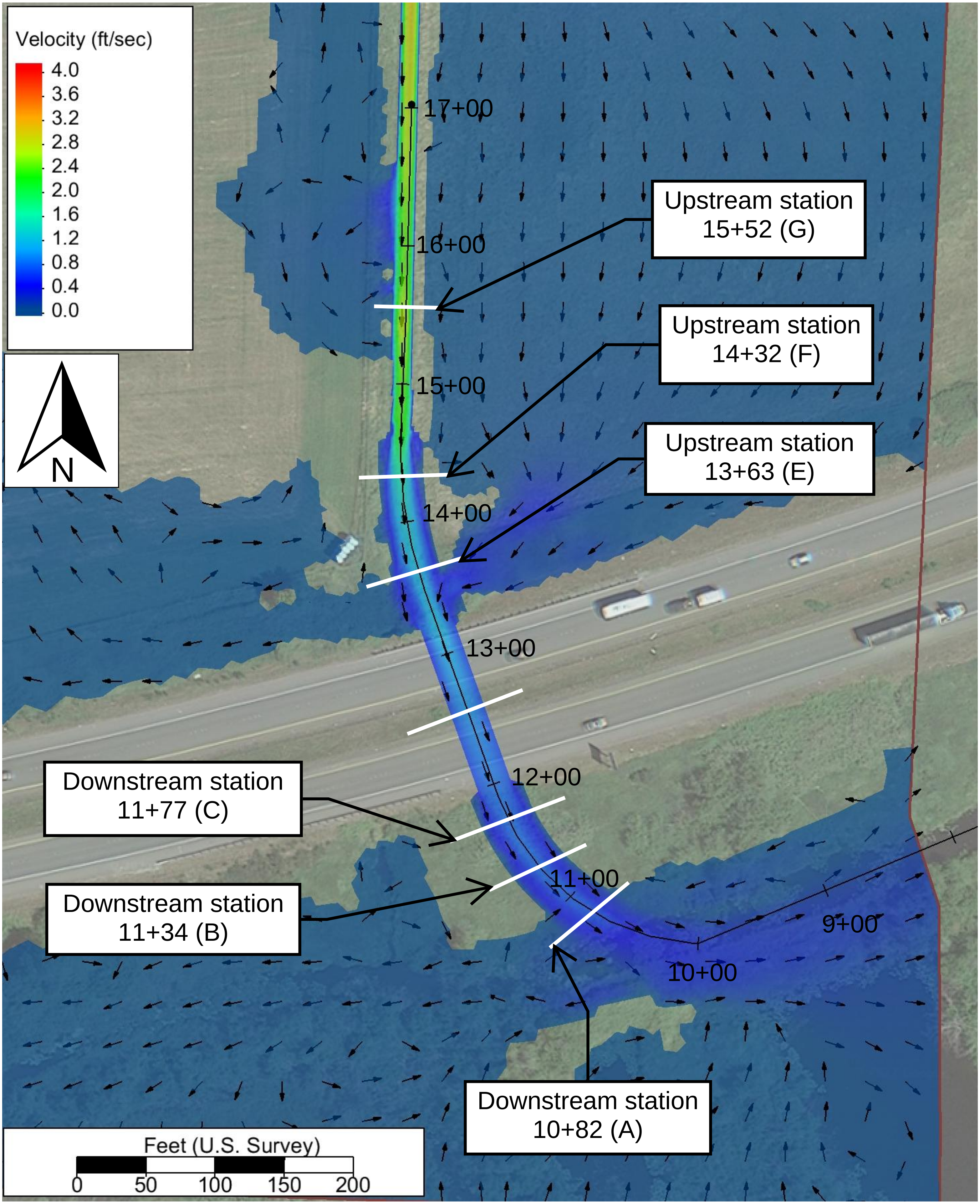


Figure H.38: Proposed conditions 2-year Vance, 2-year Chehalis velocity

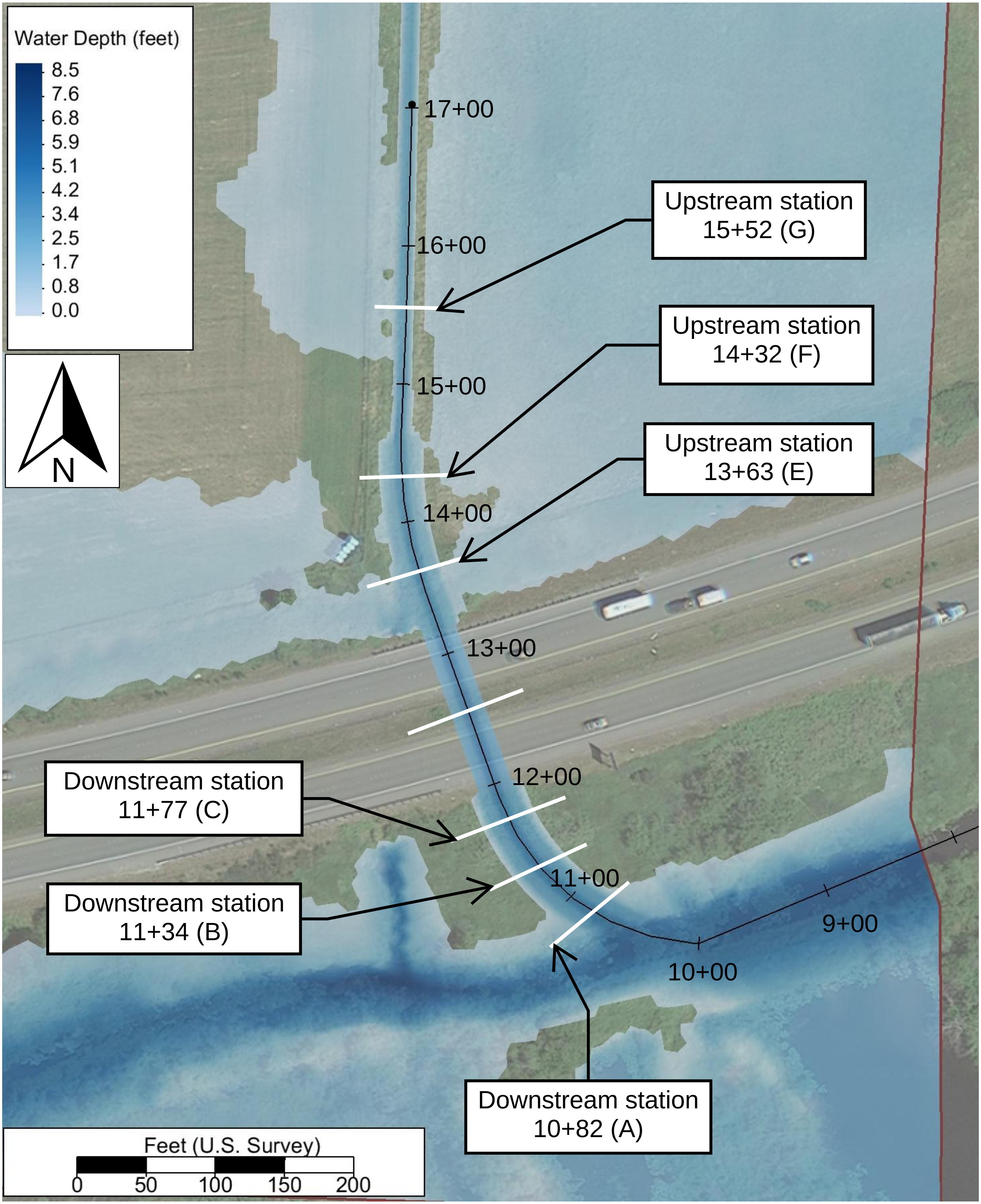


Figure H.39: Proposed conditions 2-year Vance, 2-year Chehalis water depth

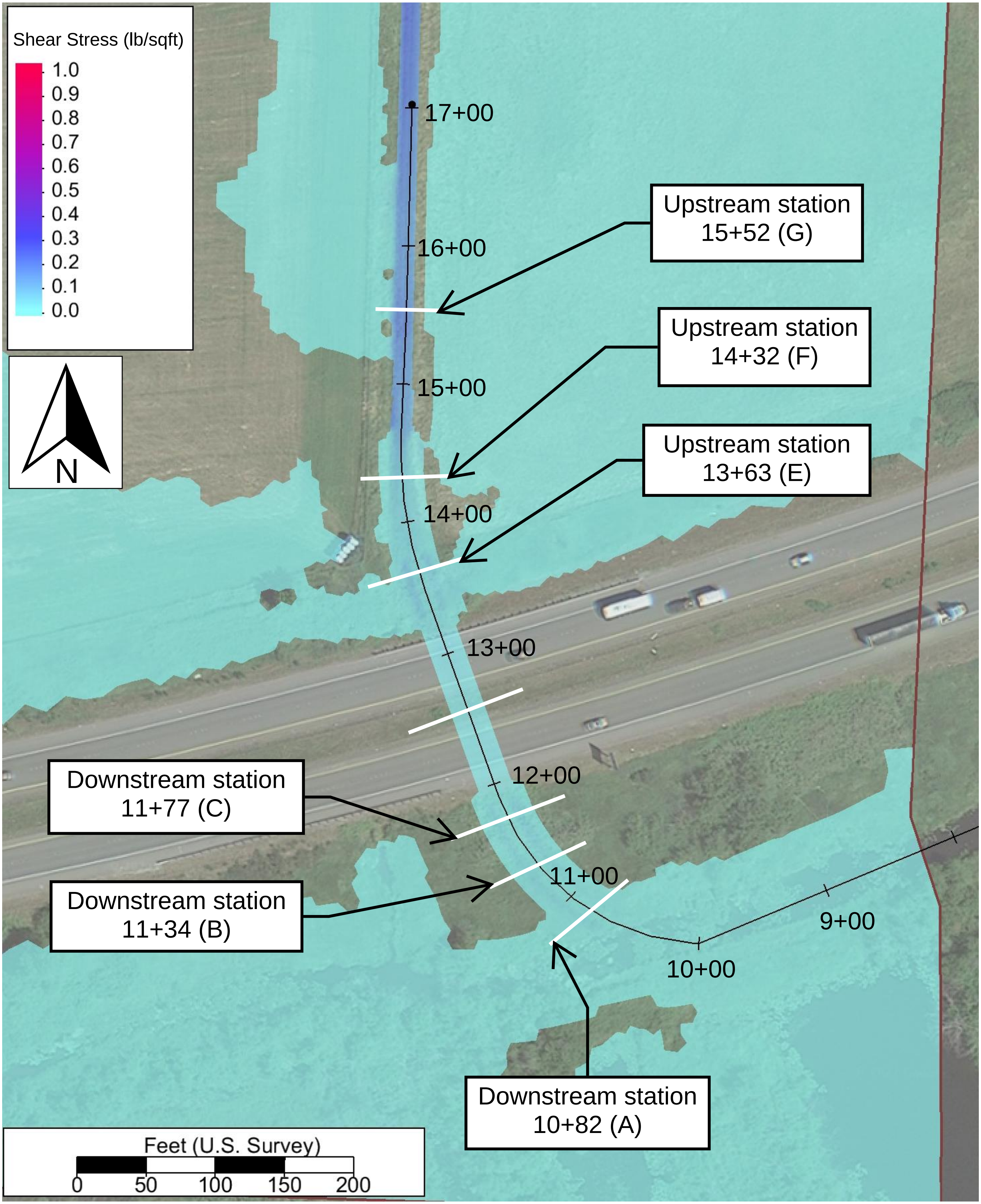


Figure H.40: Proposed conditions 2-year Vance, 2-year Chehalis shear stress

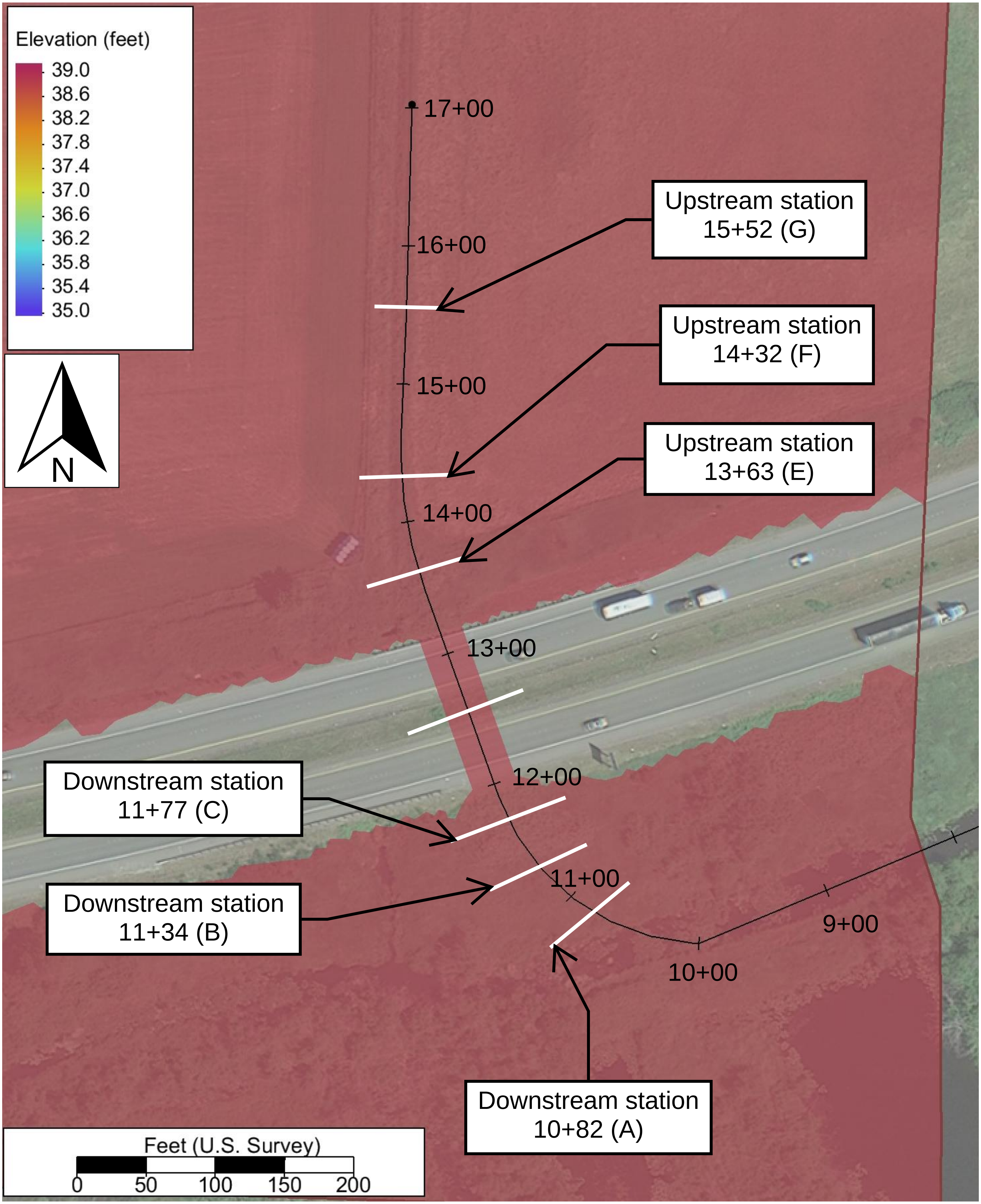


Figure H.41: Proposed conditions 2-year Vance, 100-year Chehalis water surface elevation

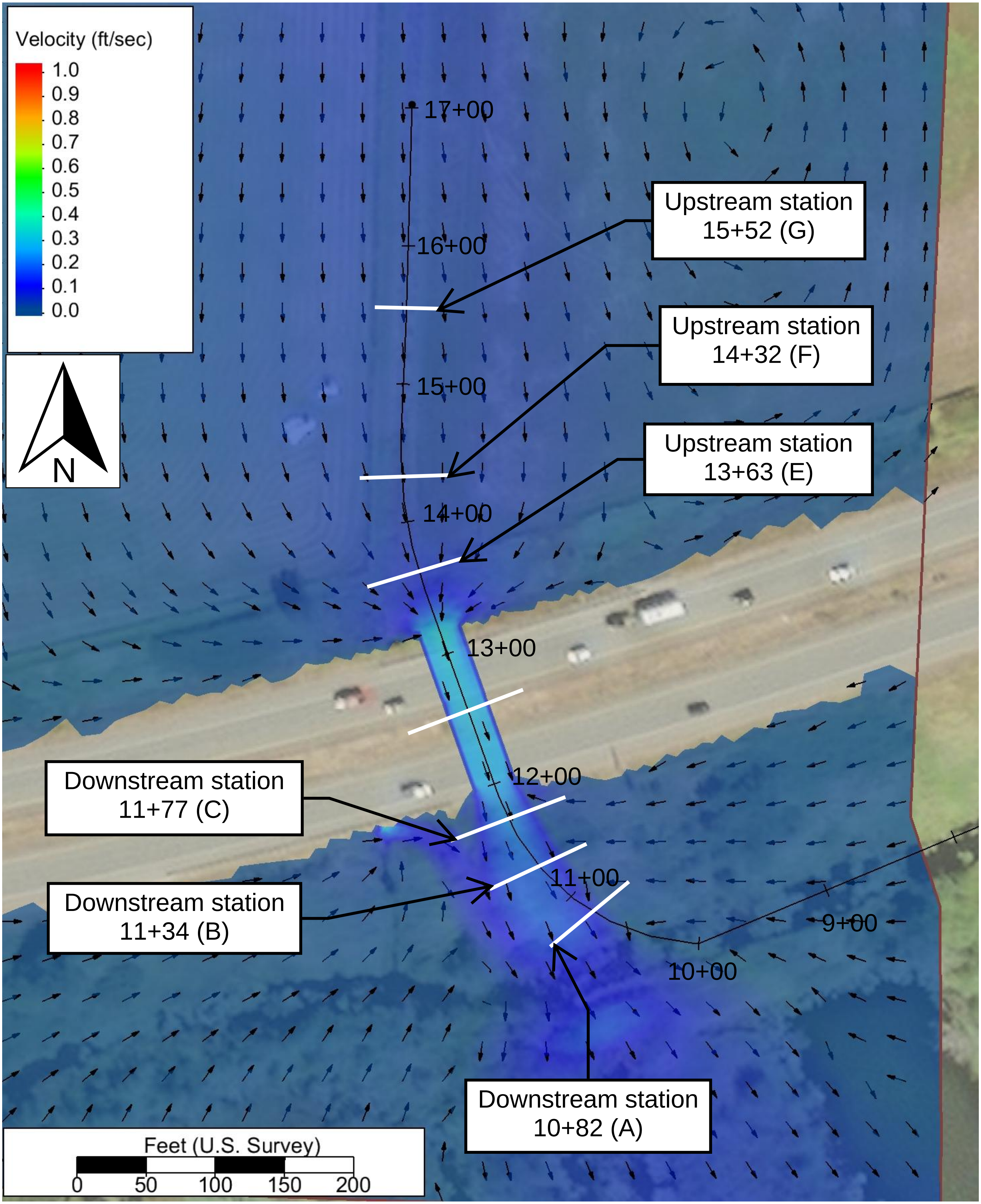


Figure H.42: Proposed conditions 2-year Vance, 100-year Chehalis velocity

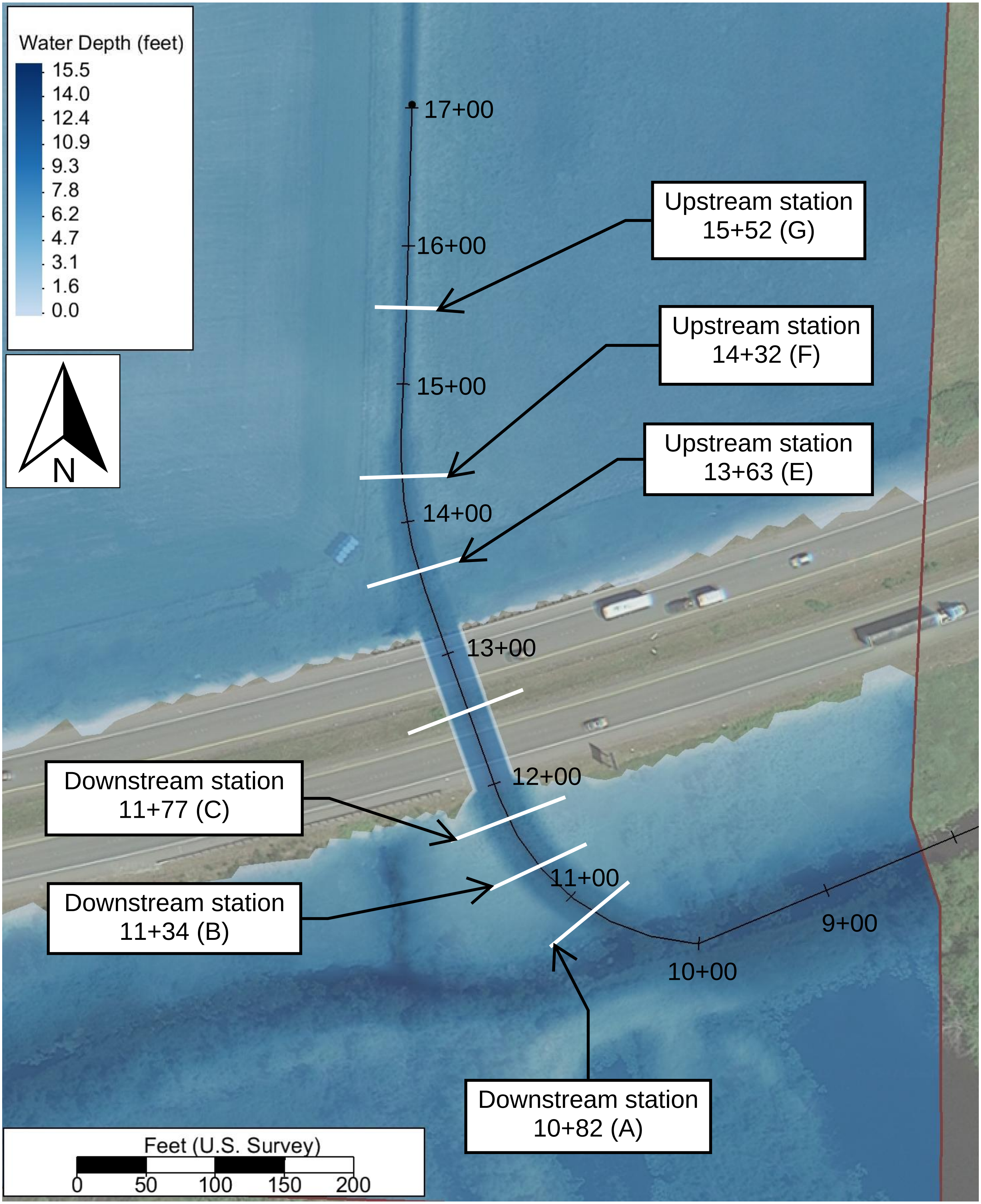


Figure H.43: Proposed conditions 2-year Vance, 100-year Chehalis water depth

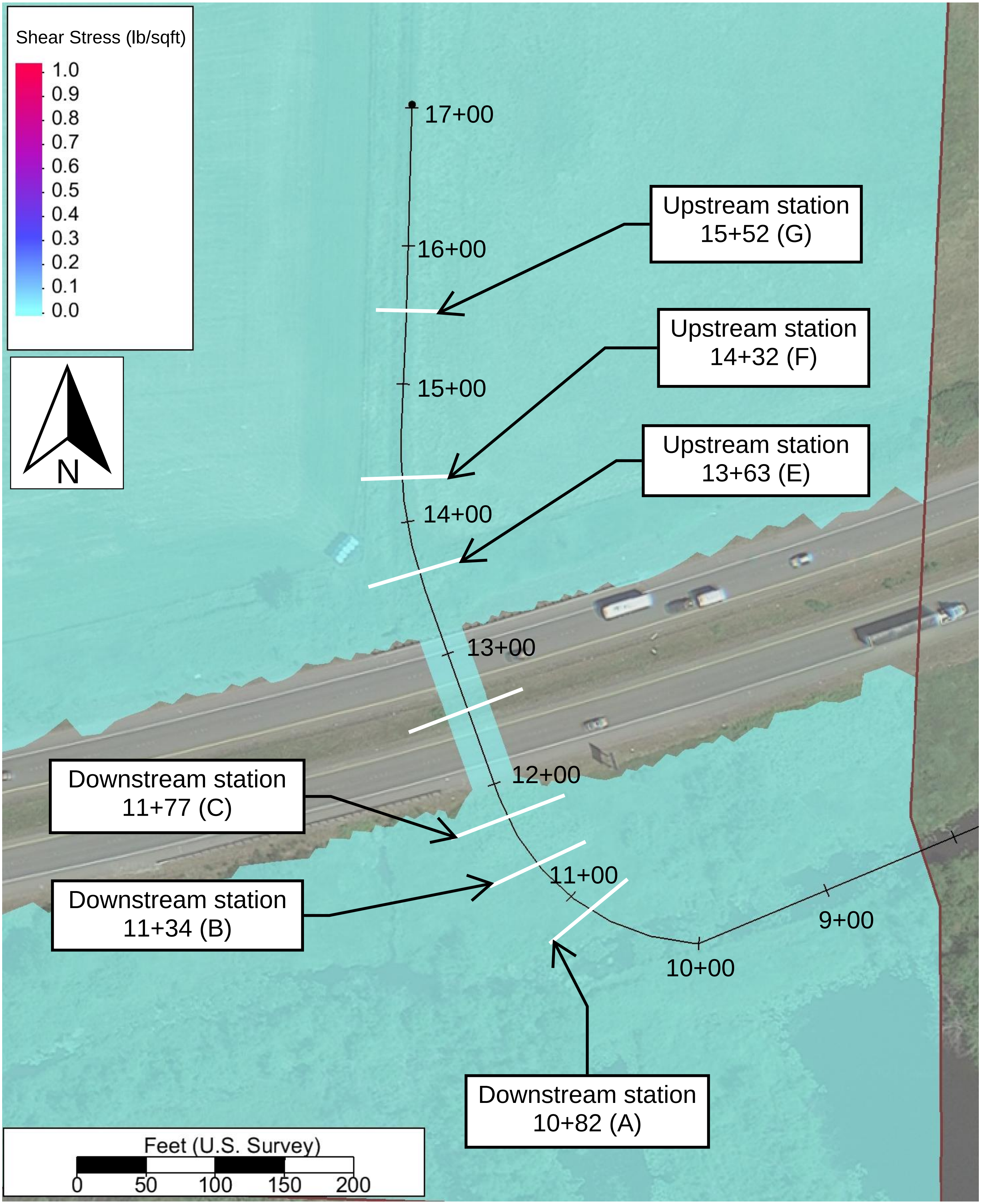


Figure H.44: Proposed conditions 2-year Vance, 100-year Chehalis shear stress

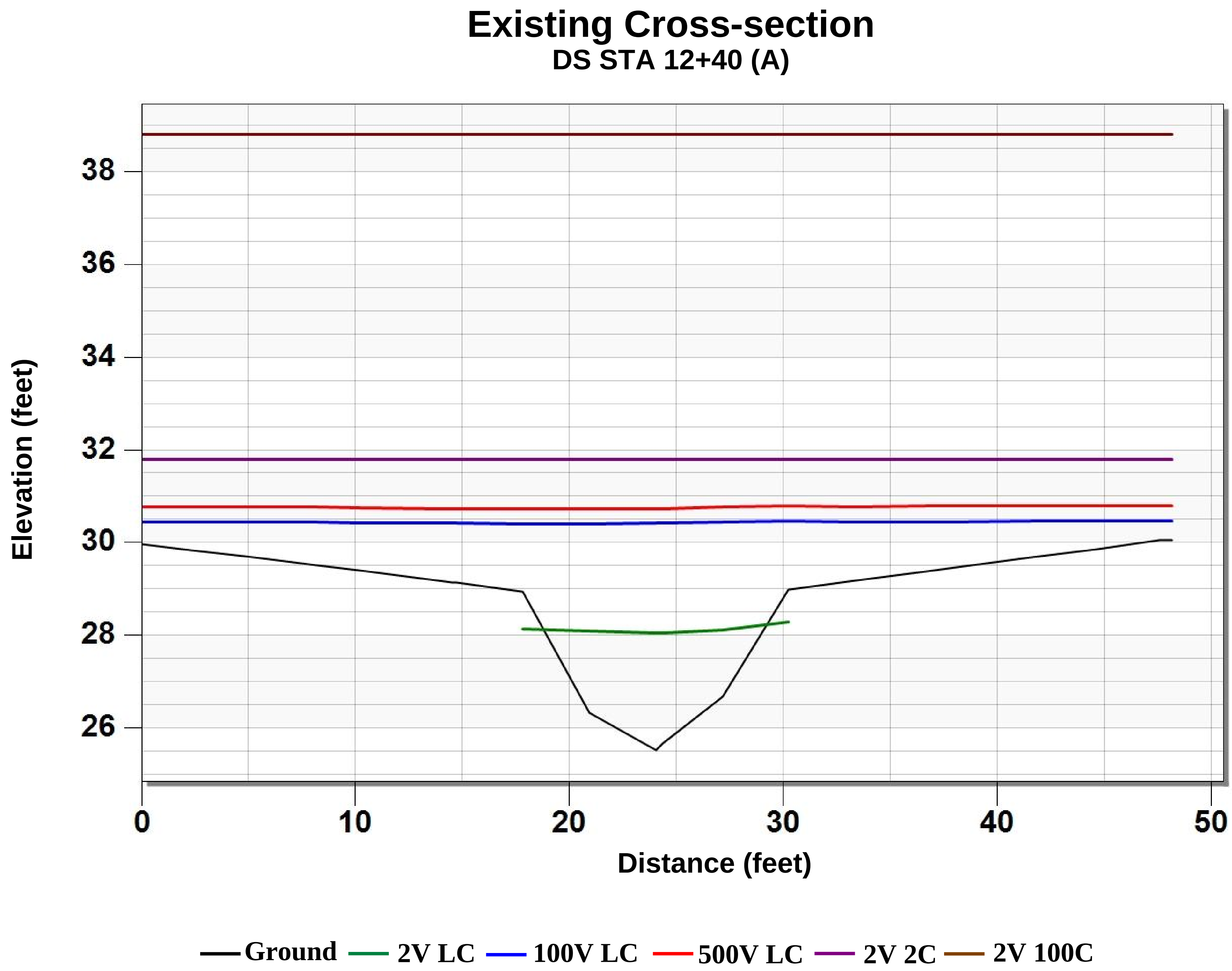


Figure H.45: Existing conditions cross section at downstream station 12+40 (A)

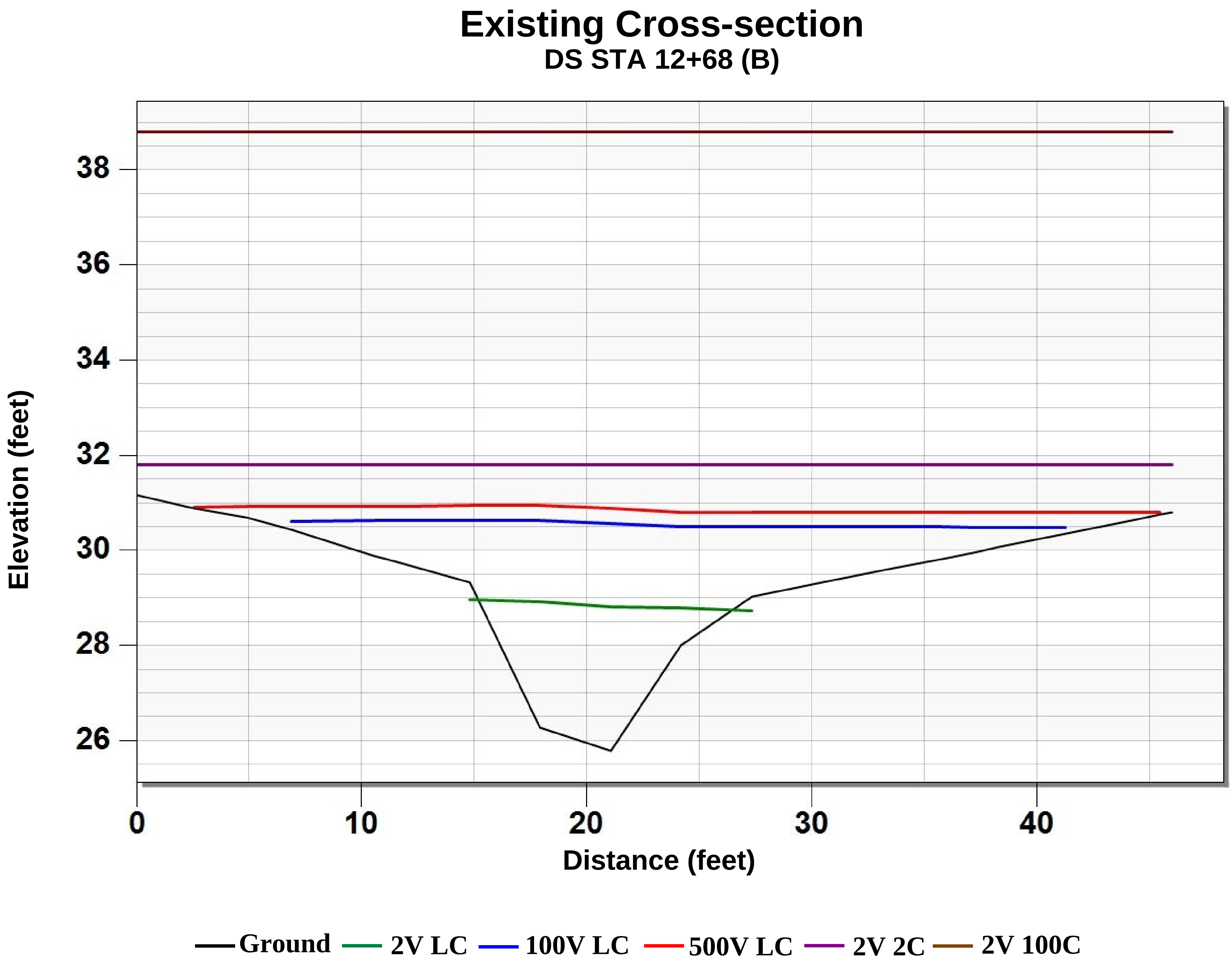


Figure H.46: Existing conditions cross section at downstream station 12+68 (B)

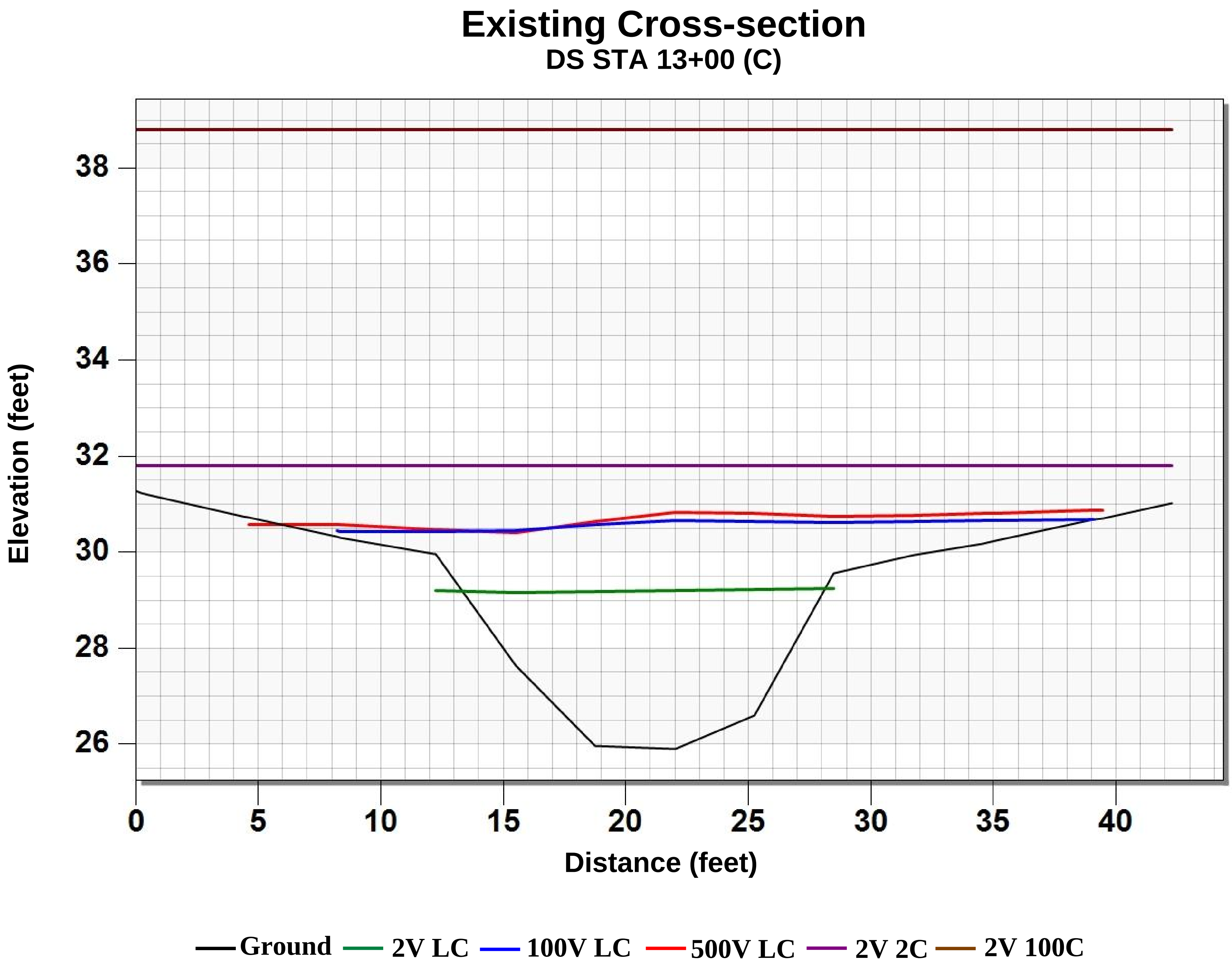


Figure H.47: Existing conditions cross section at downstream station 13+00 (C)

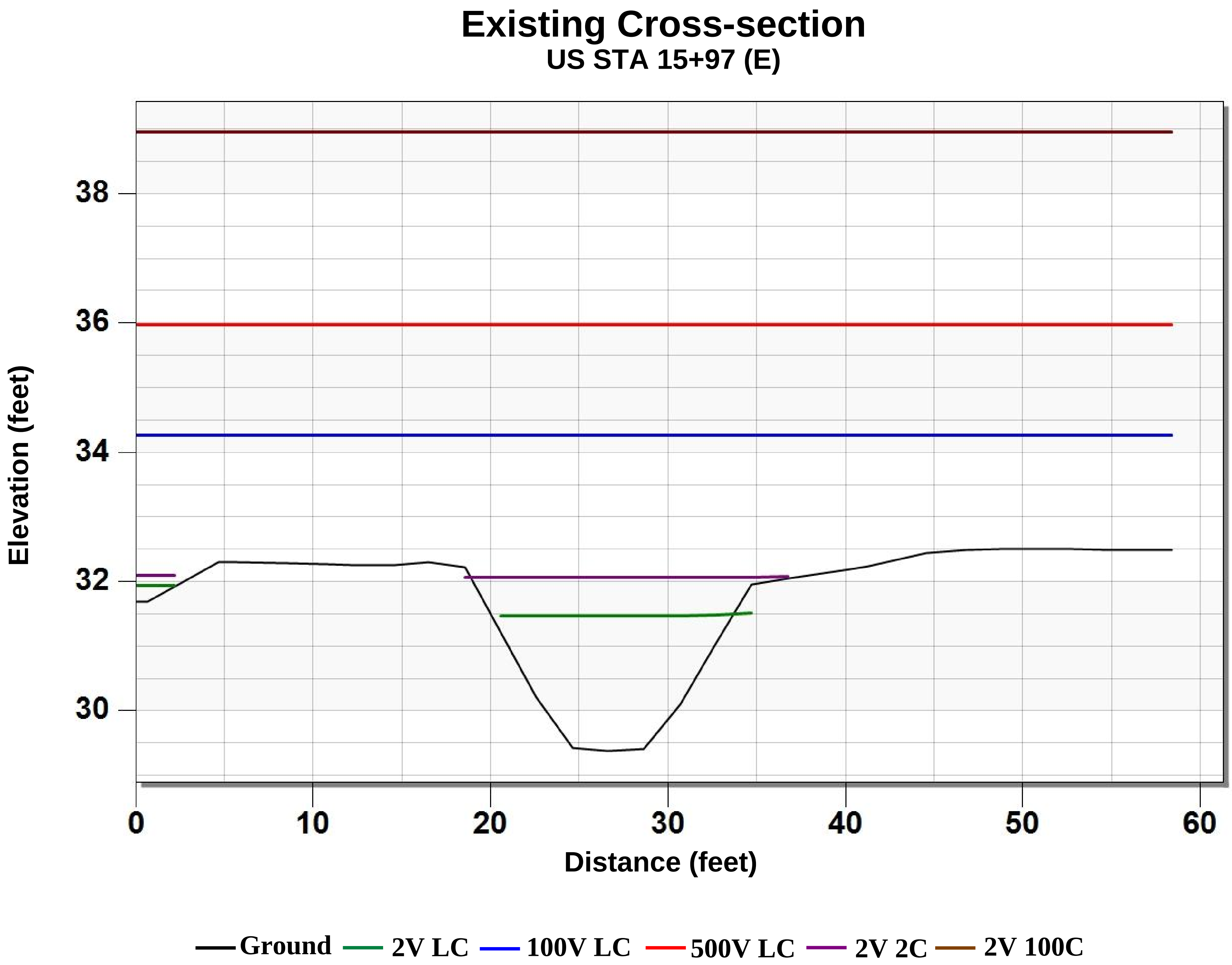


Figure H.48: Existing conditions cross section at upstream station 15+97 (E)

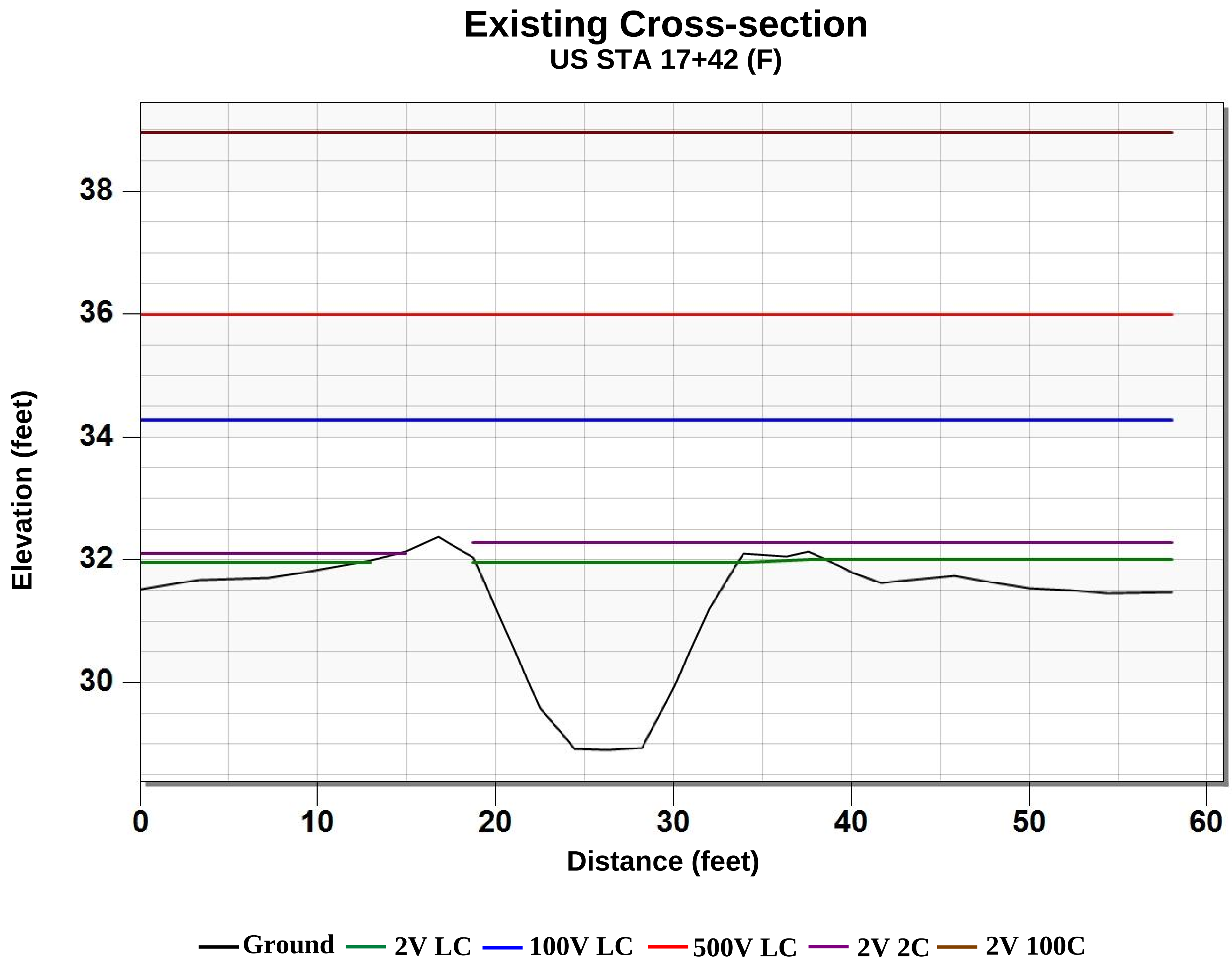


Figure H.49: Existing conditions cross section at upstream station 17+42 (F)

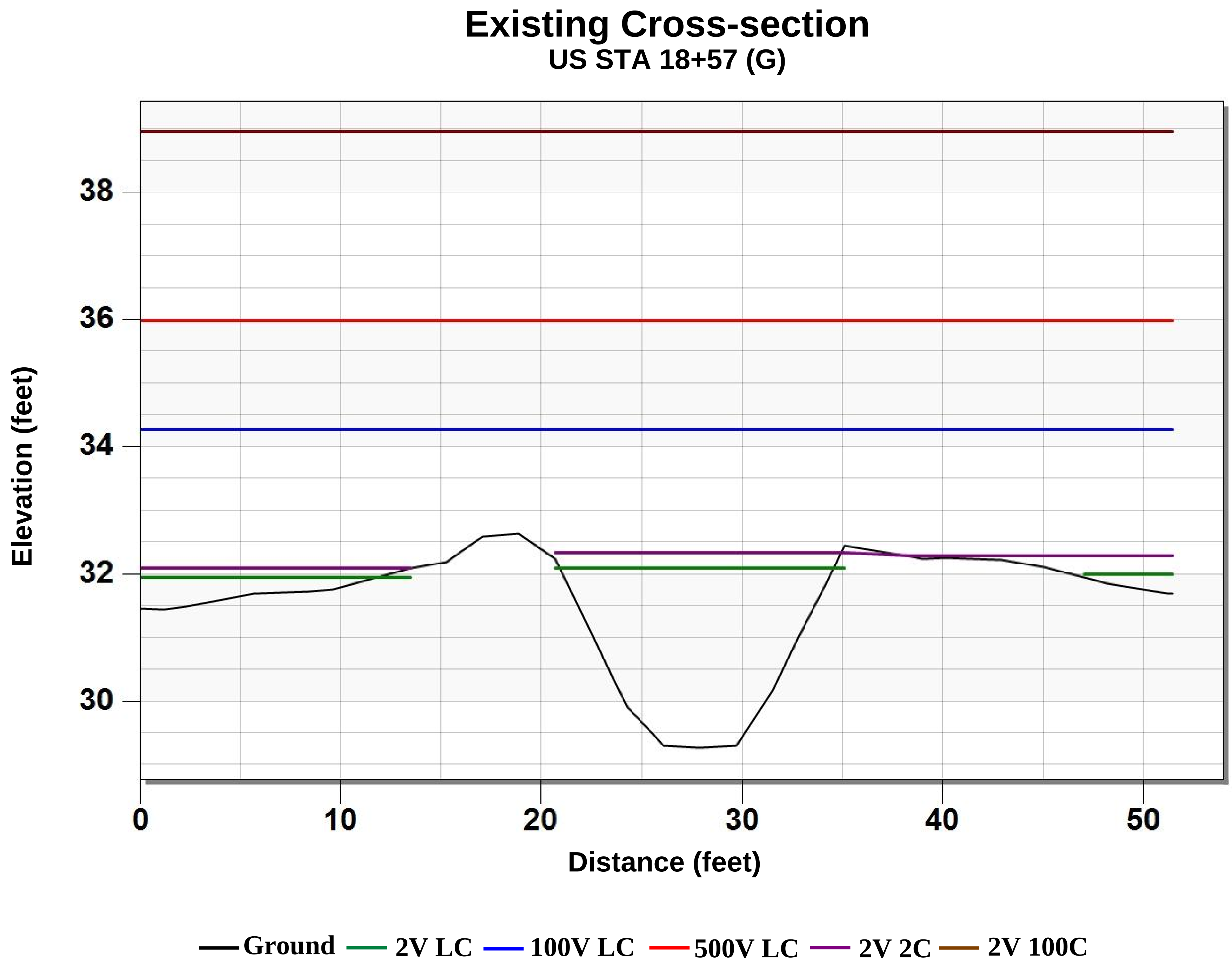


Figure H.50: Existing conditions cross section at upstream station 18+57 (G)

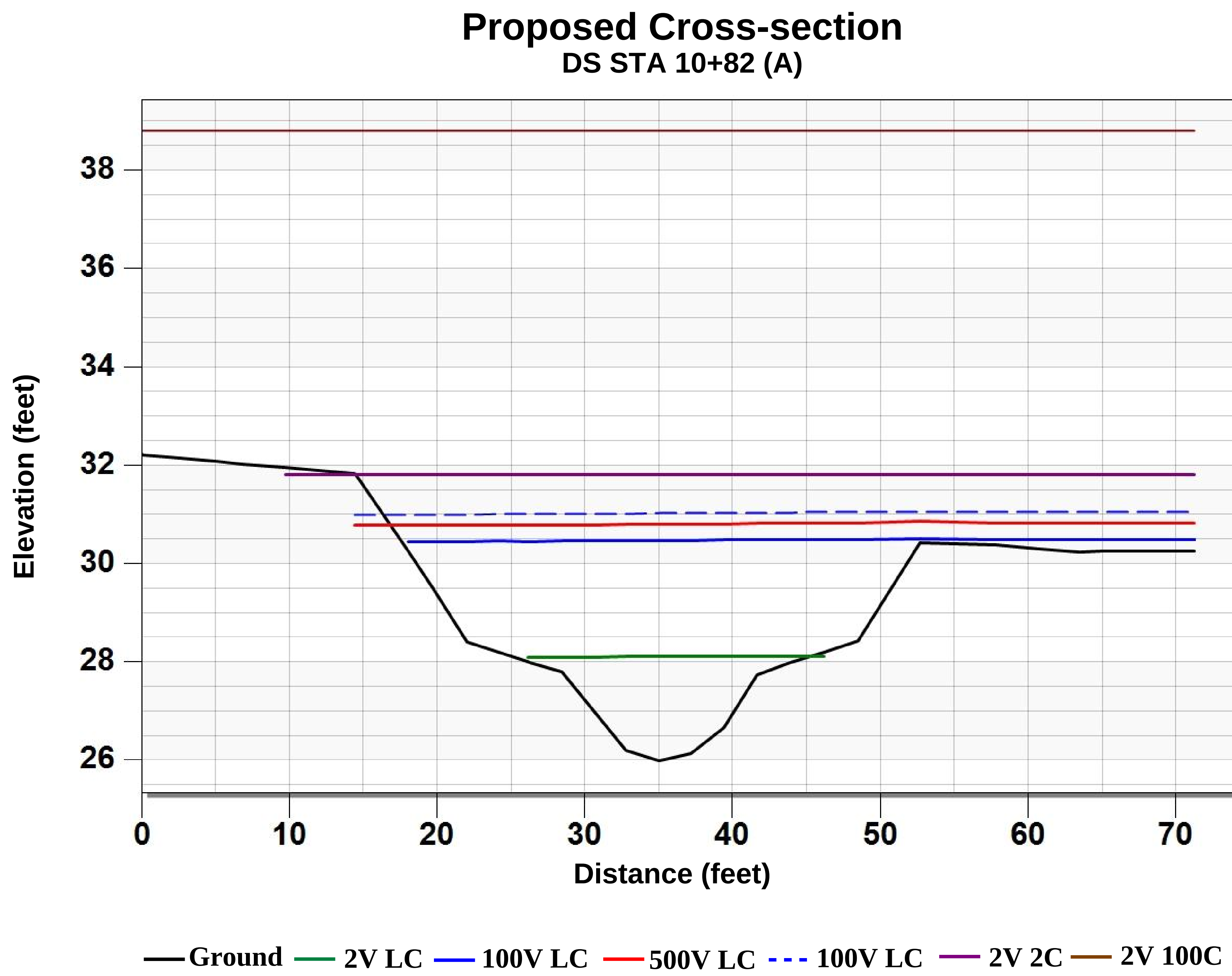


Figure H.51: Proposed conditions cross section at downstream station 10+82 (A)

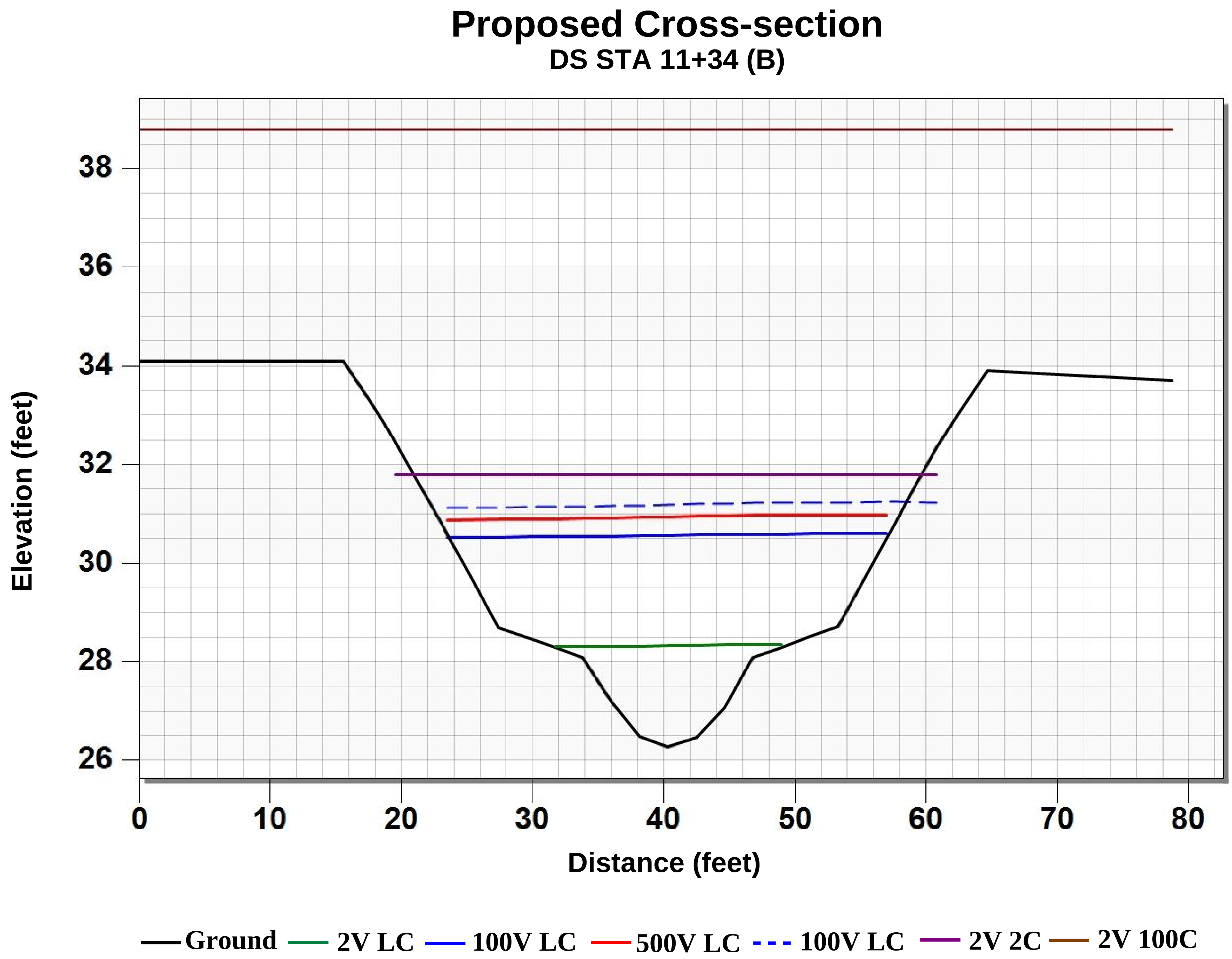


Figure H.52: Proposed conditions cross section at downstream station 11+34 (B)

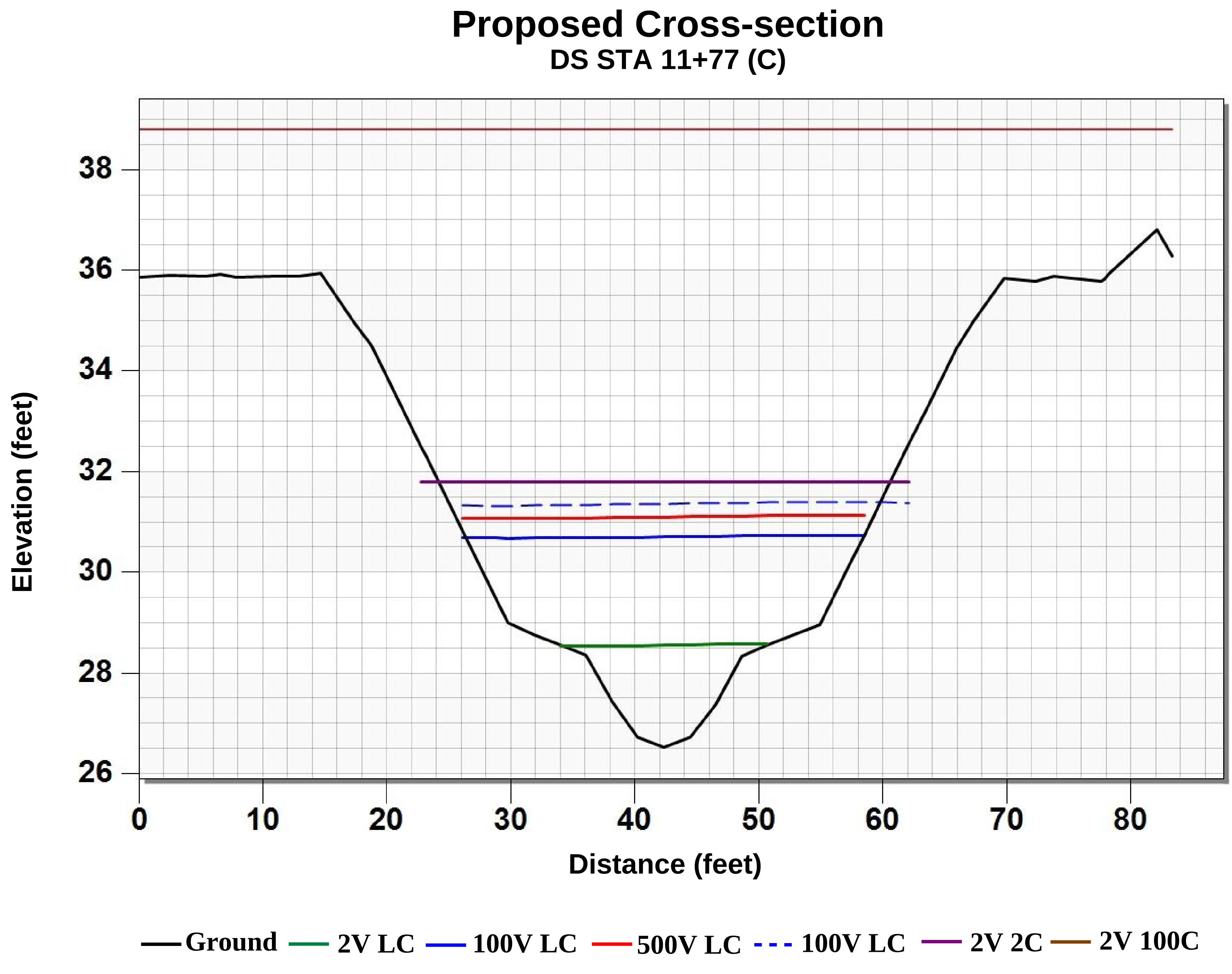


Figure H.53: Proposed conditions cross section at downstream station 11+77 (C)

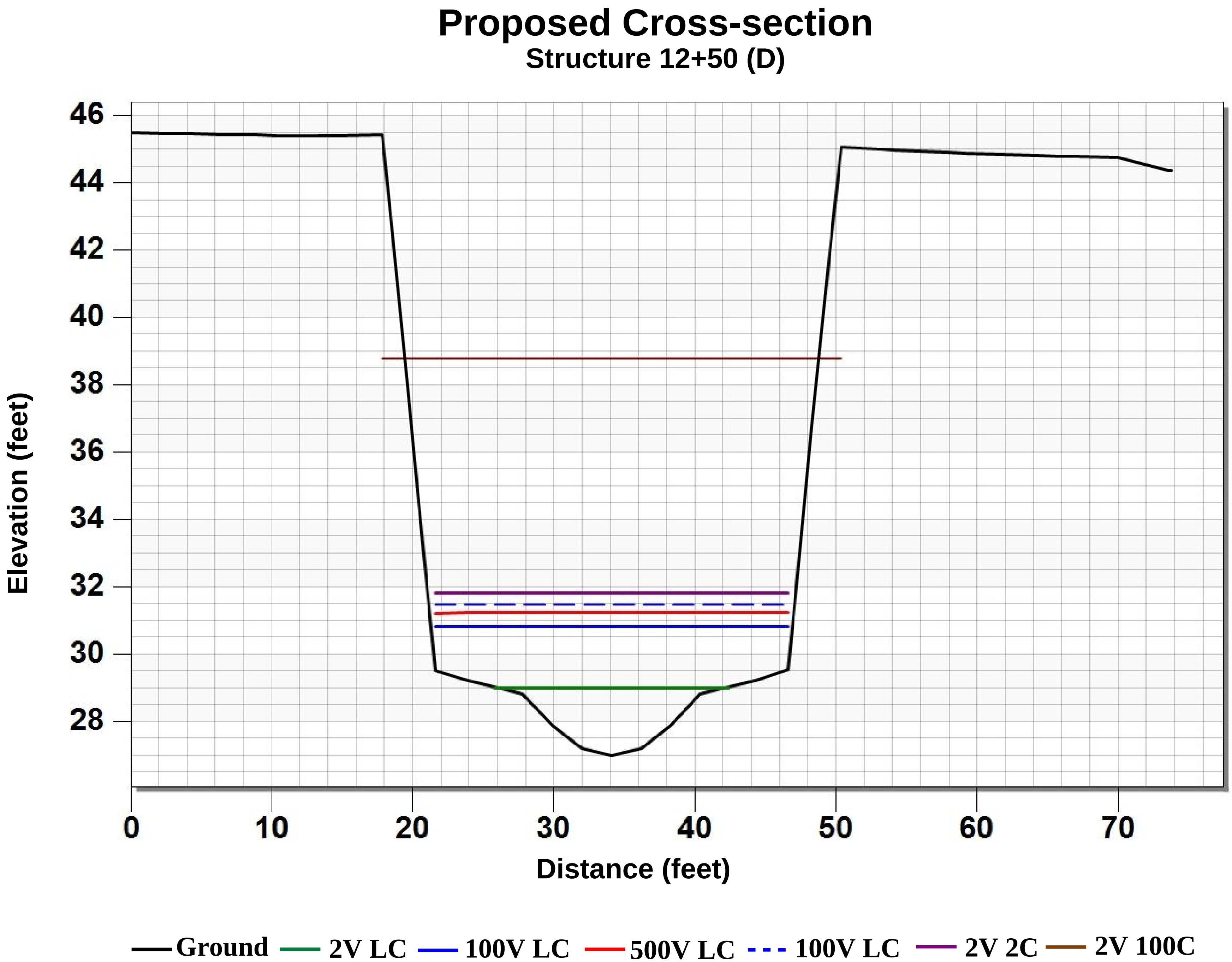


Figure H.54: Proposed conditions cross section at the structure 12+50 (D)

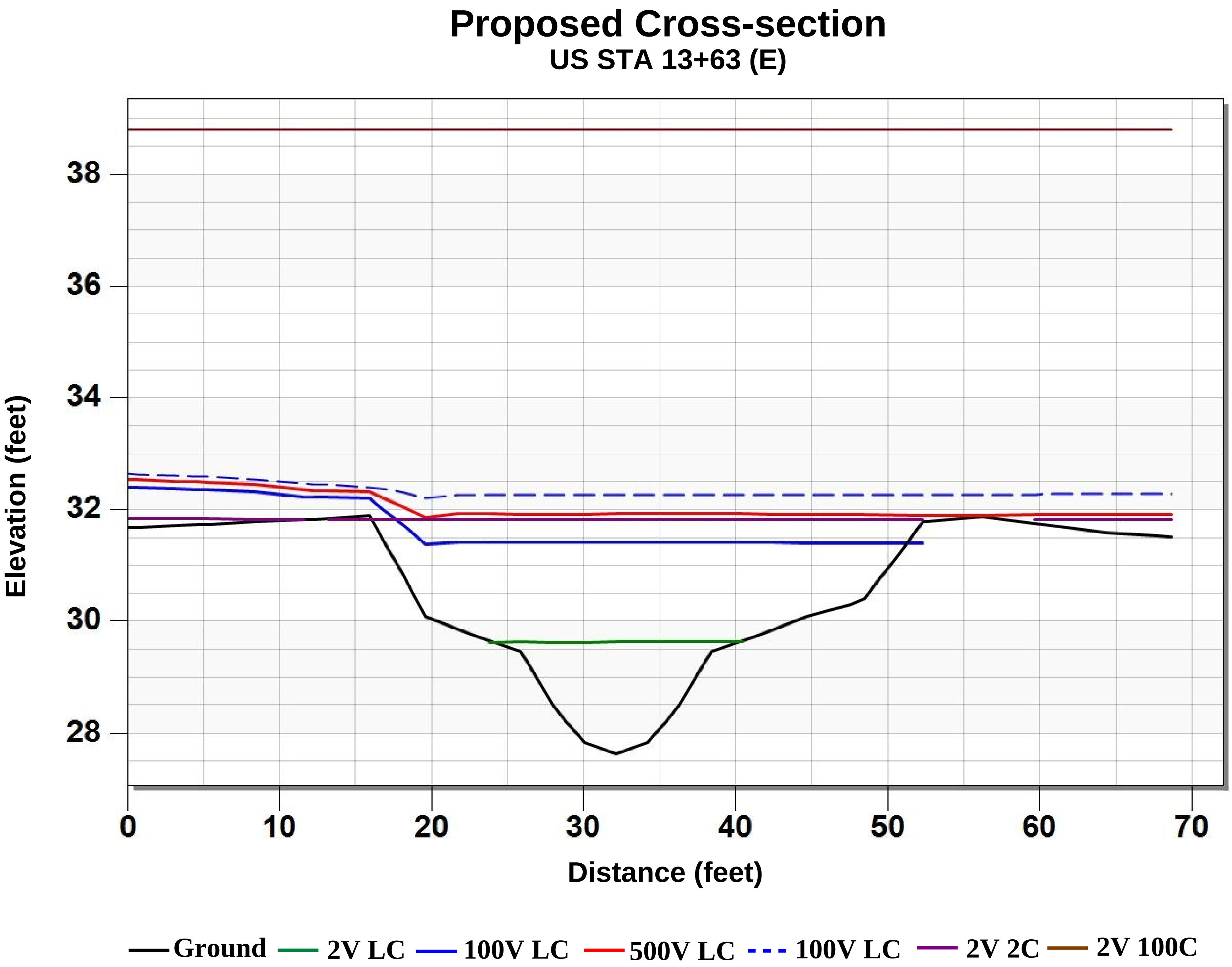


Figure H.55: Proposed conditions cross section at upstream station 13+63 (E)

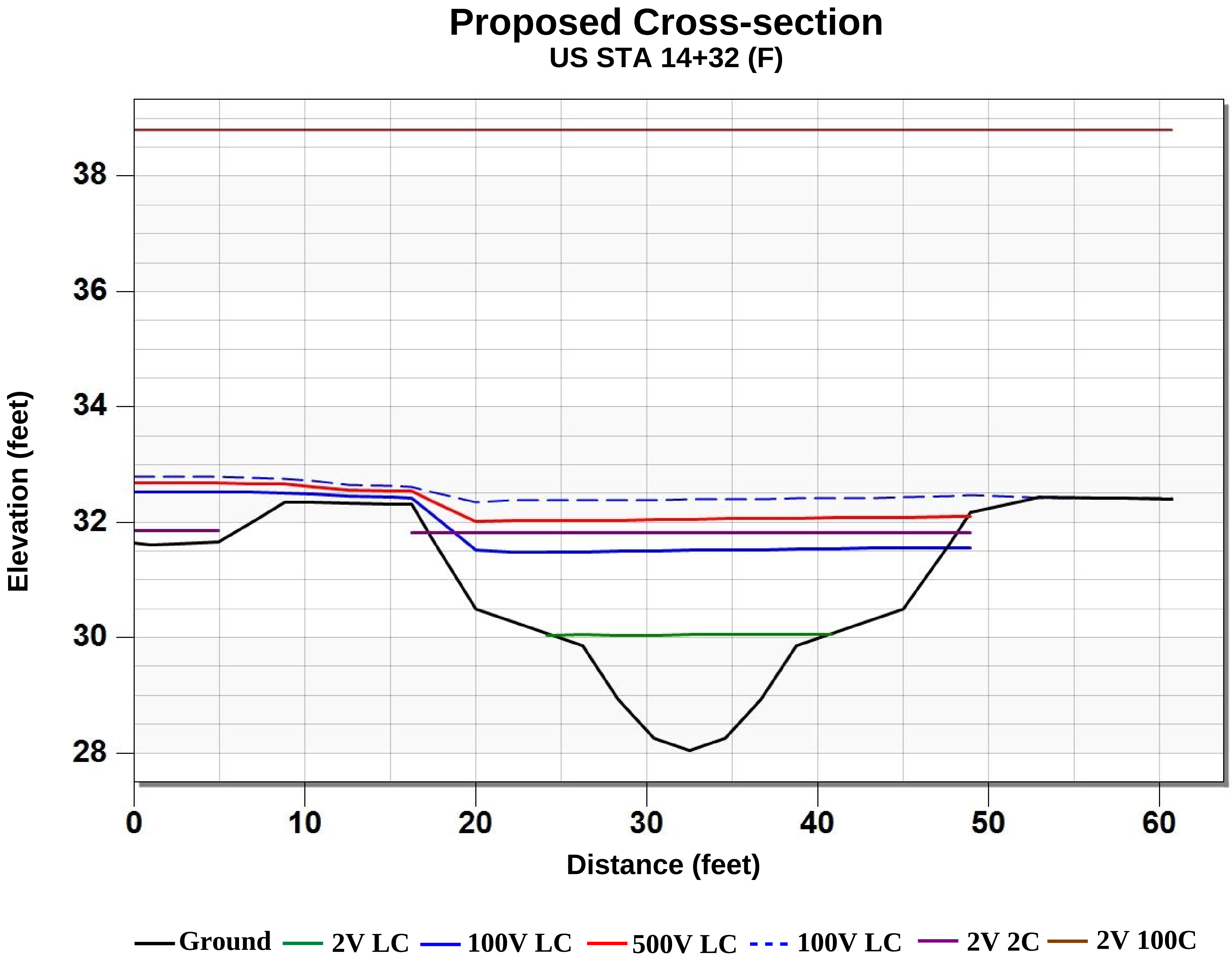


Figure H.56: Proposed conditions cross section at upstream station 14+32 (F)

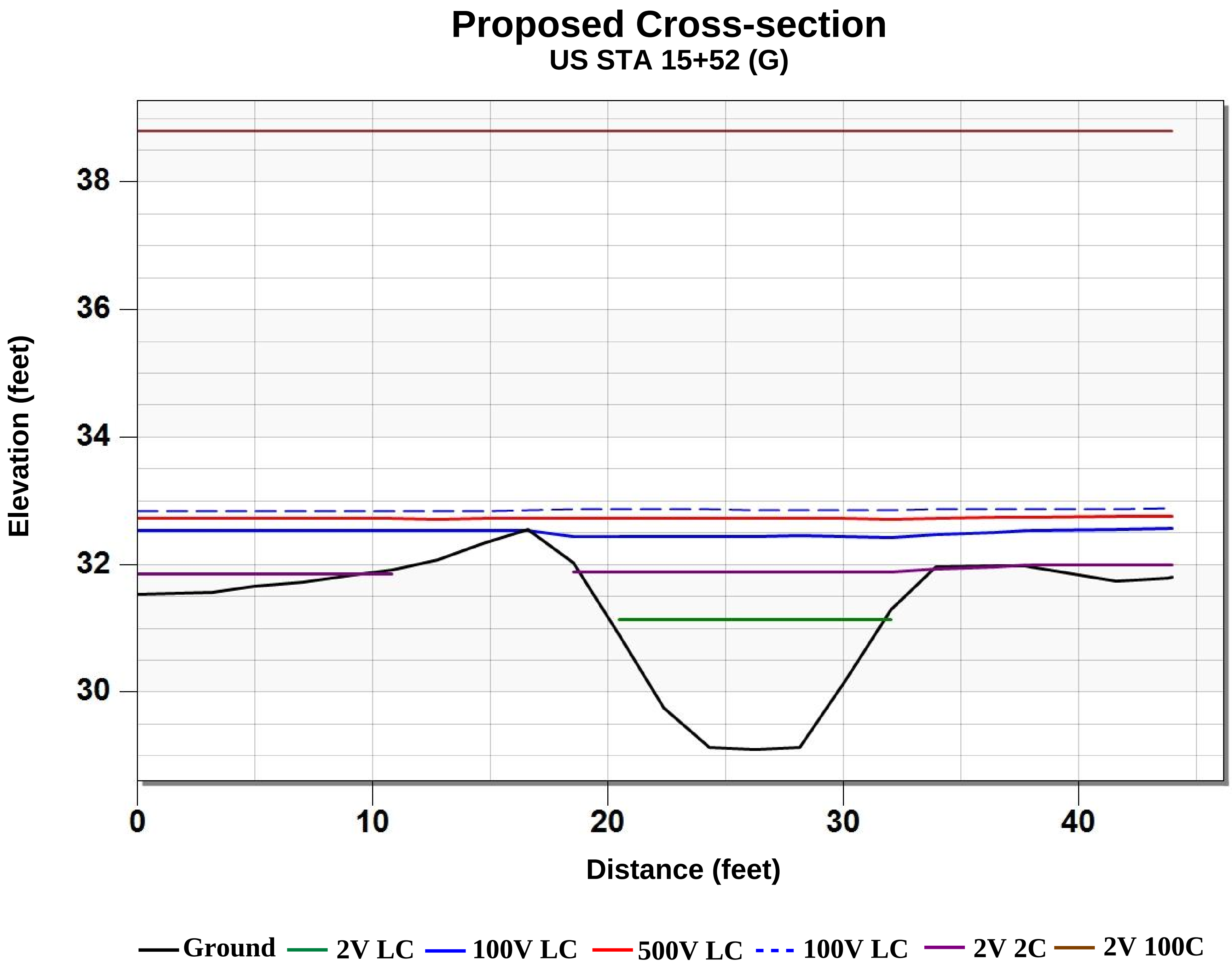


Figure H.57: Proposed conditions cross section at upstream station 15+52 (G)

Appendix I: SRH-2D Model Stability and Continuity

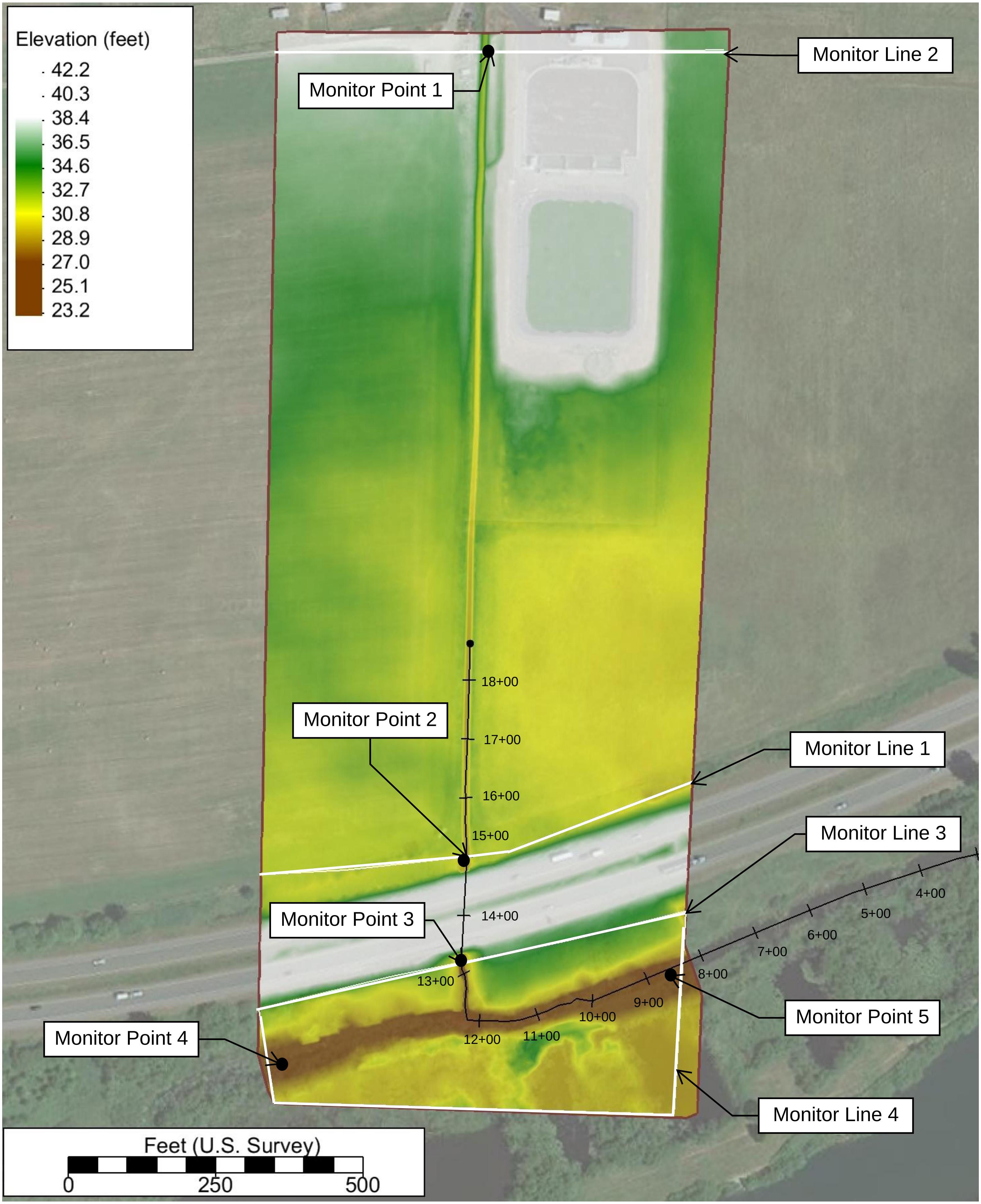


Figure I.1: Existing conditions monitor points and lines

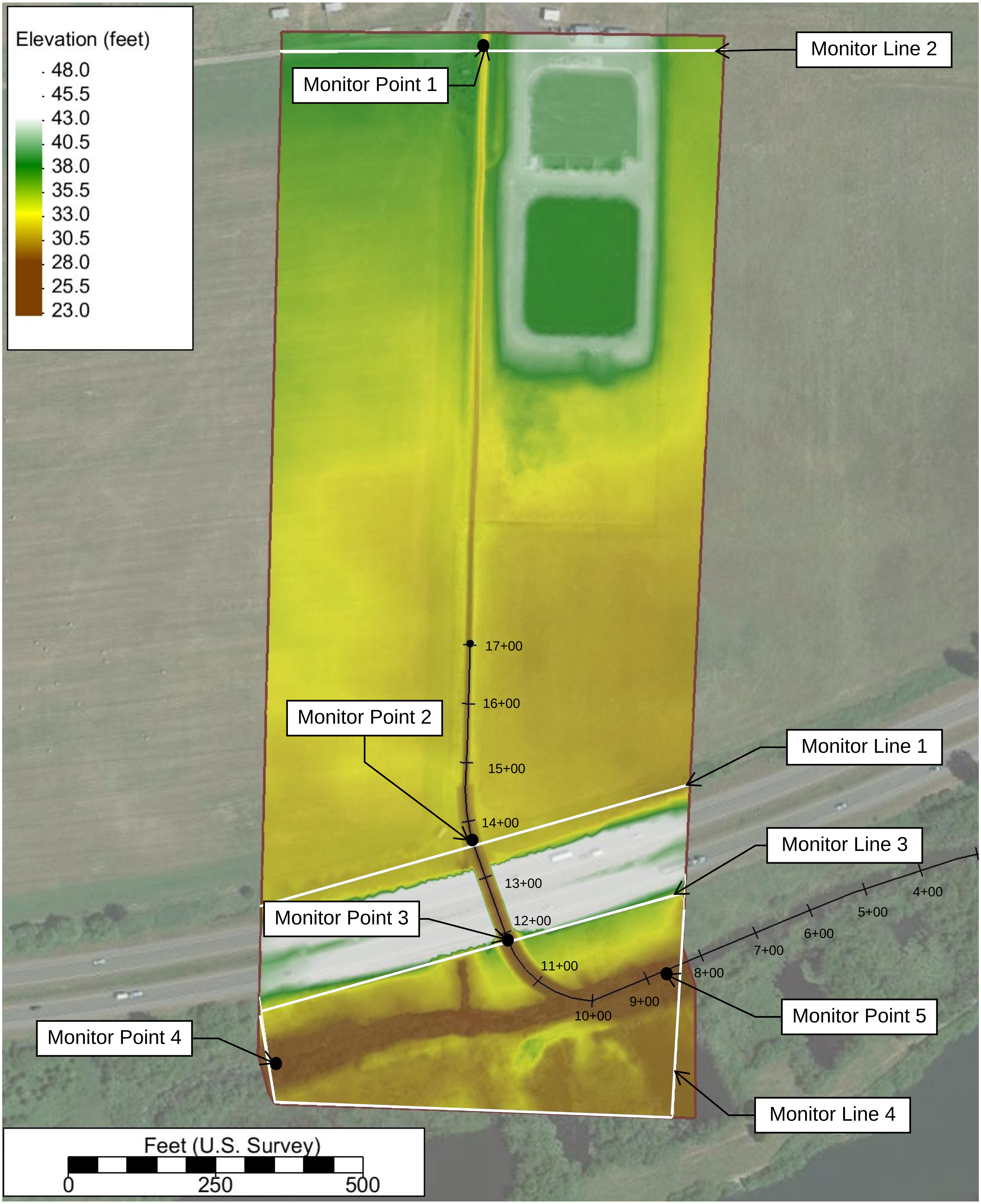


Figure I.2: Proposed conditions monitor points and lines

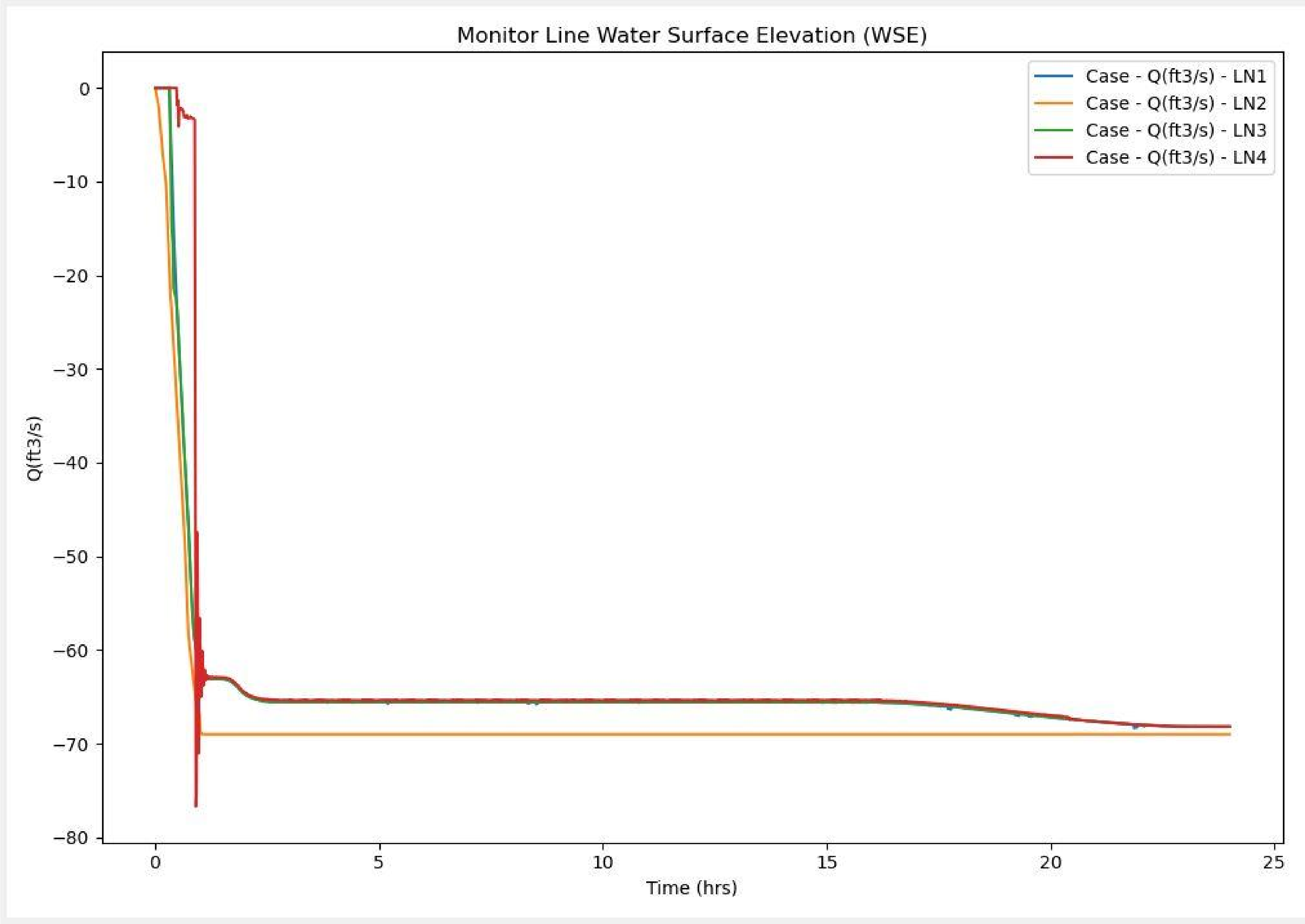


Figure I.3: Existing conditions 2-year Vance, low flow Chehalis monitor lines

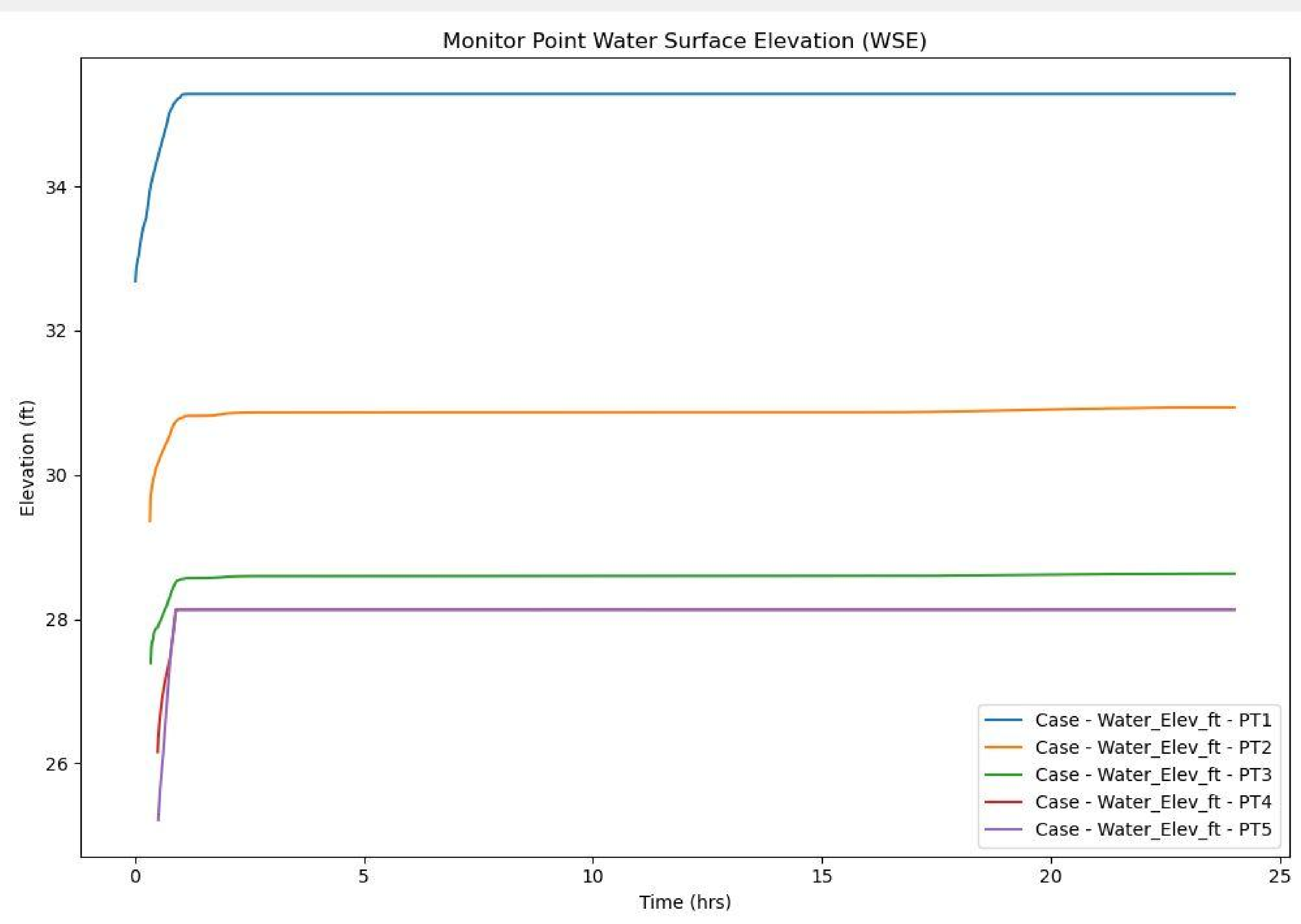


Figure I.4: Existing conditions 2-year Vance, low flow Chehalis monitor points

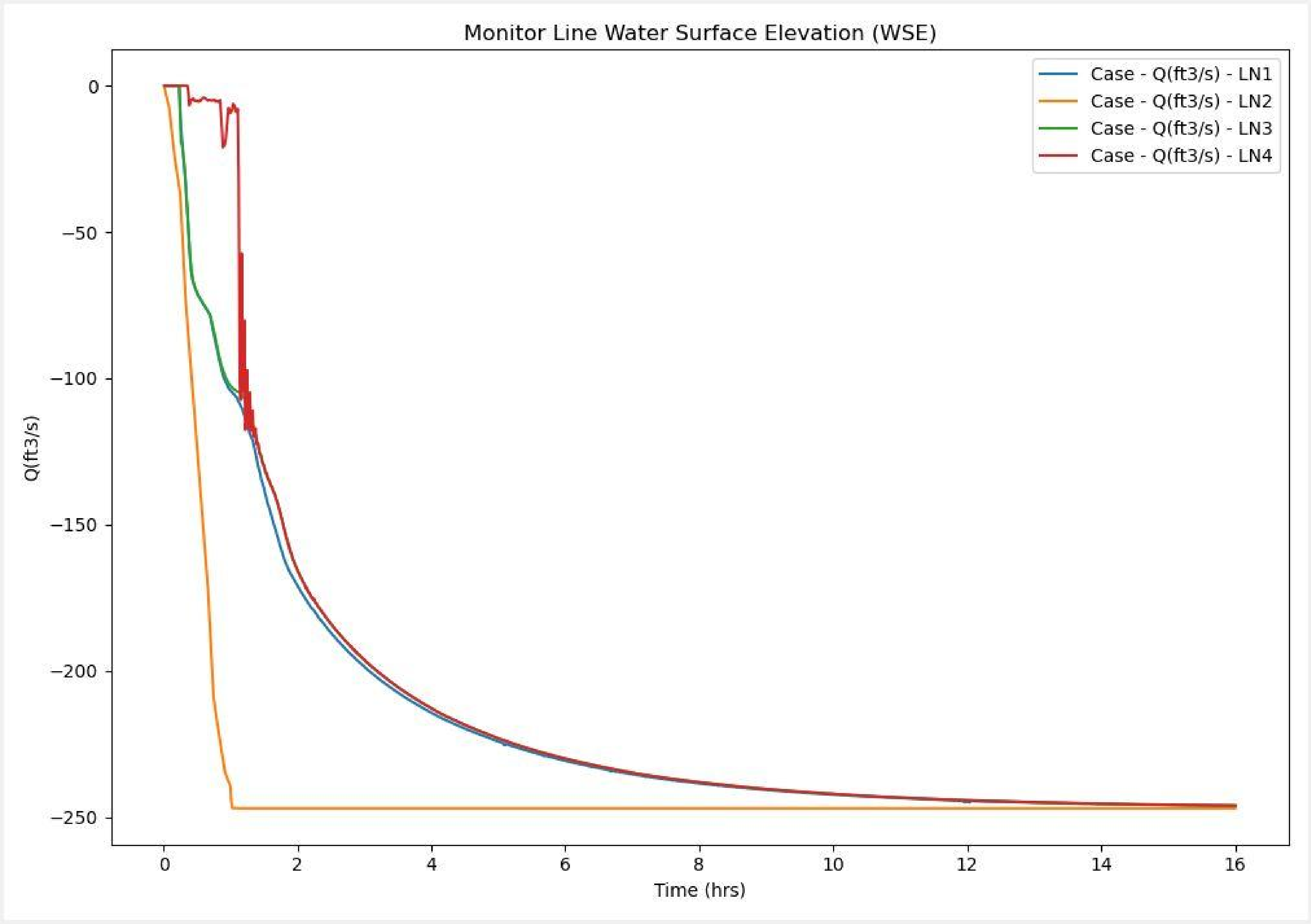


Figure I.5: Existing conditions 100-year Vance, low flow Chehalis monitor lines

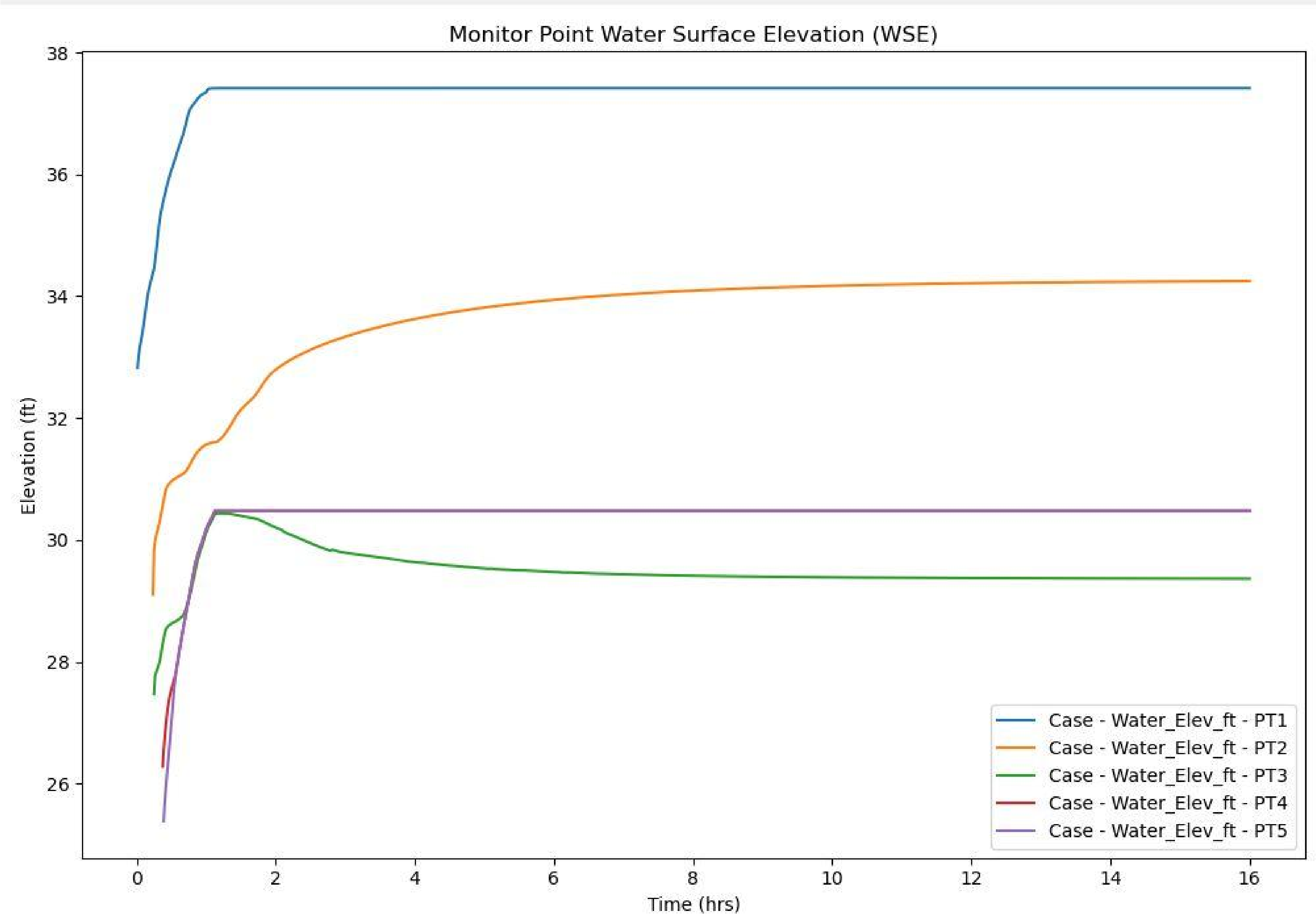


Figure I.6: Existing conditions 100-year Vance, low flow Chehalis monitor points

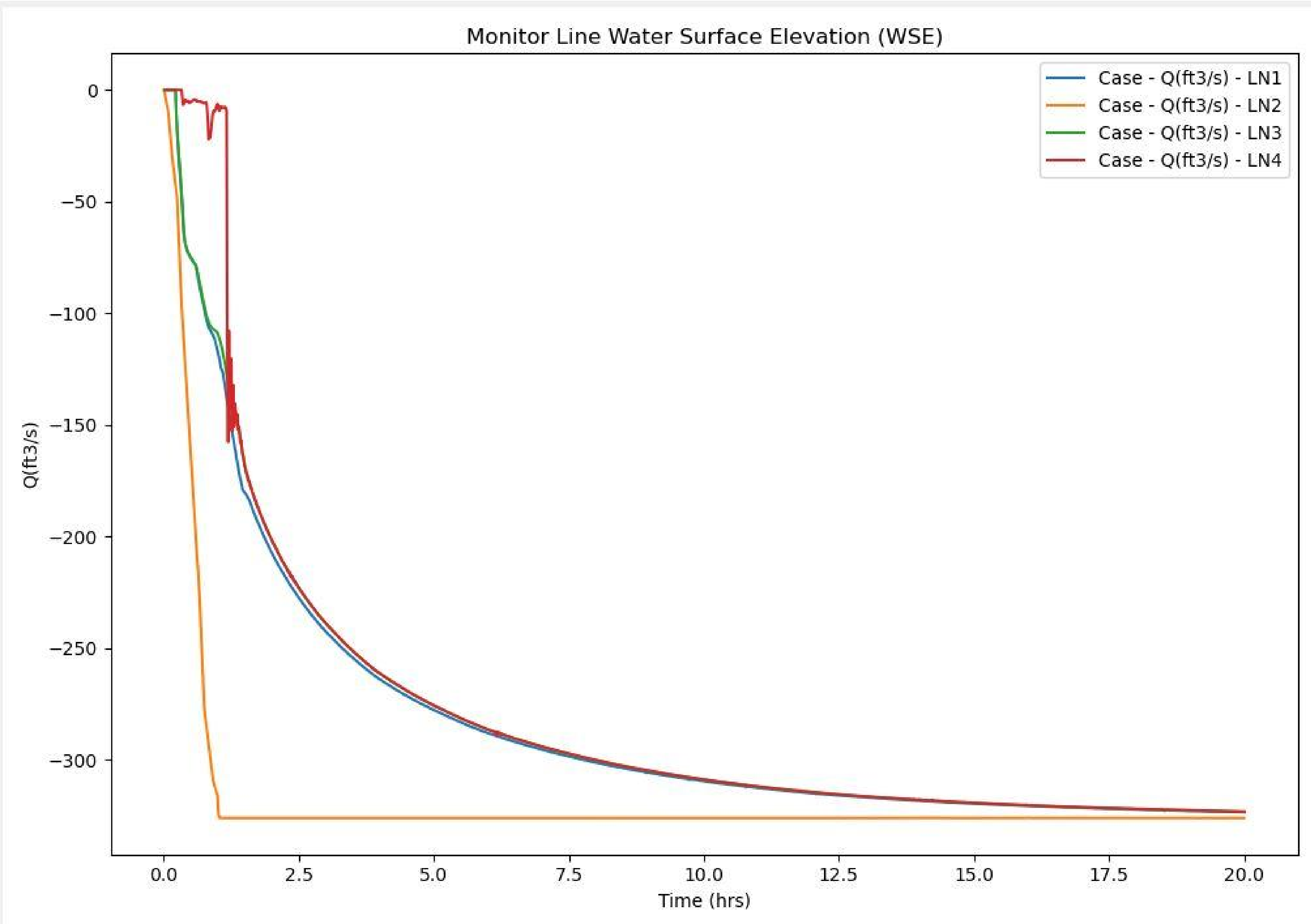


Figure I.7: Existing conditions 500-year Vance, low flow Chehalis monitor lines

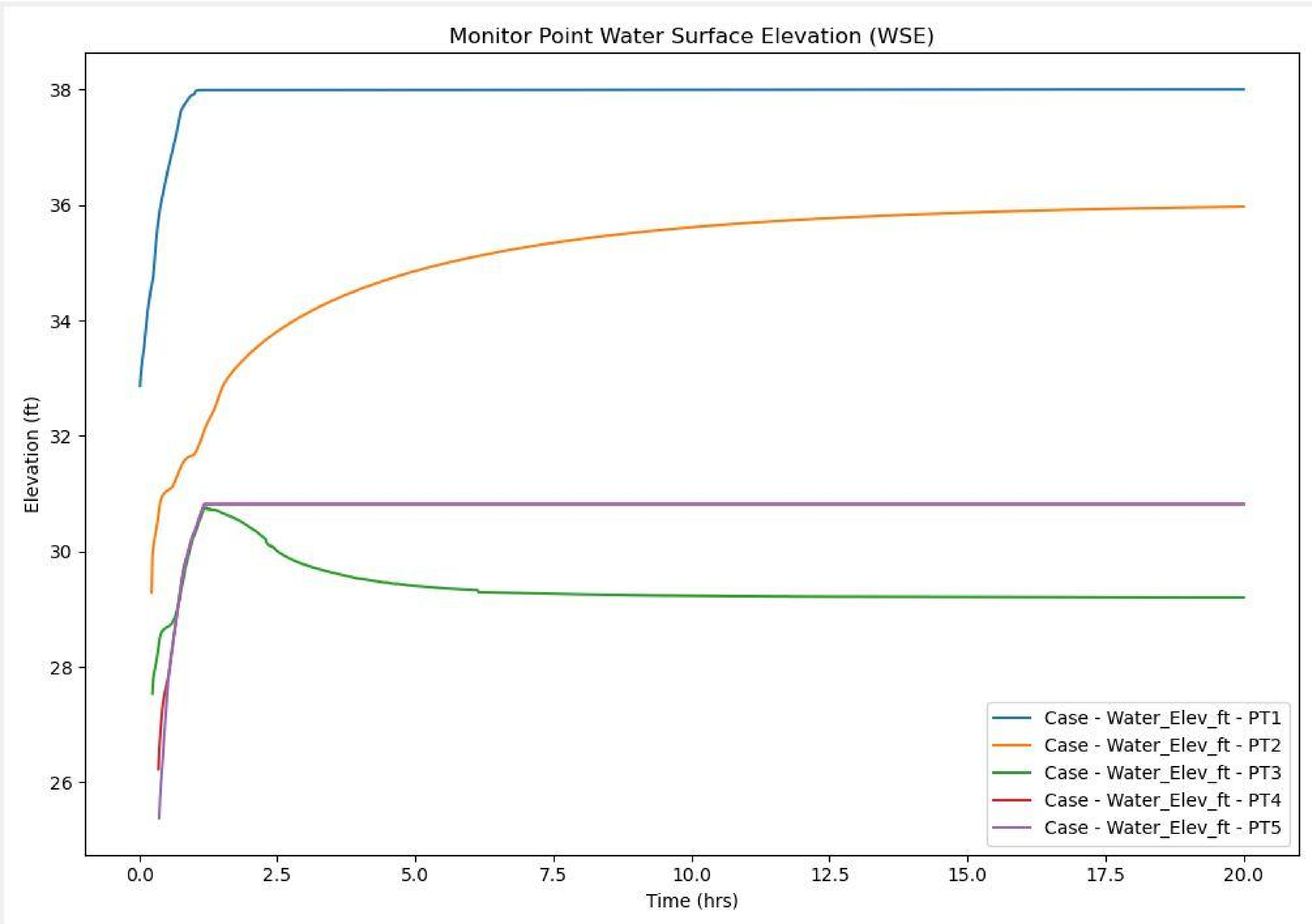


Figure I.8: Existing conditions 500-year Vance, low flow Chehalis monitor points

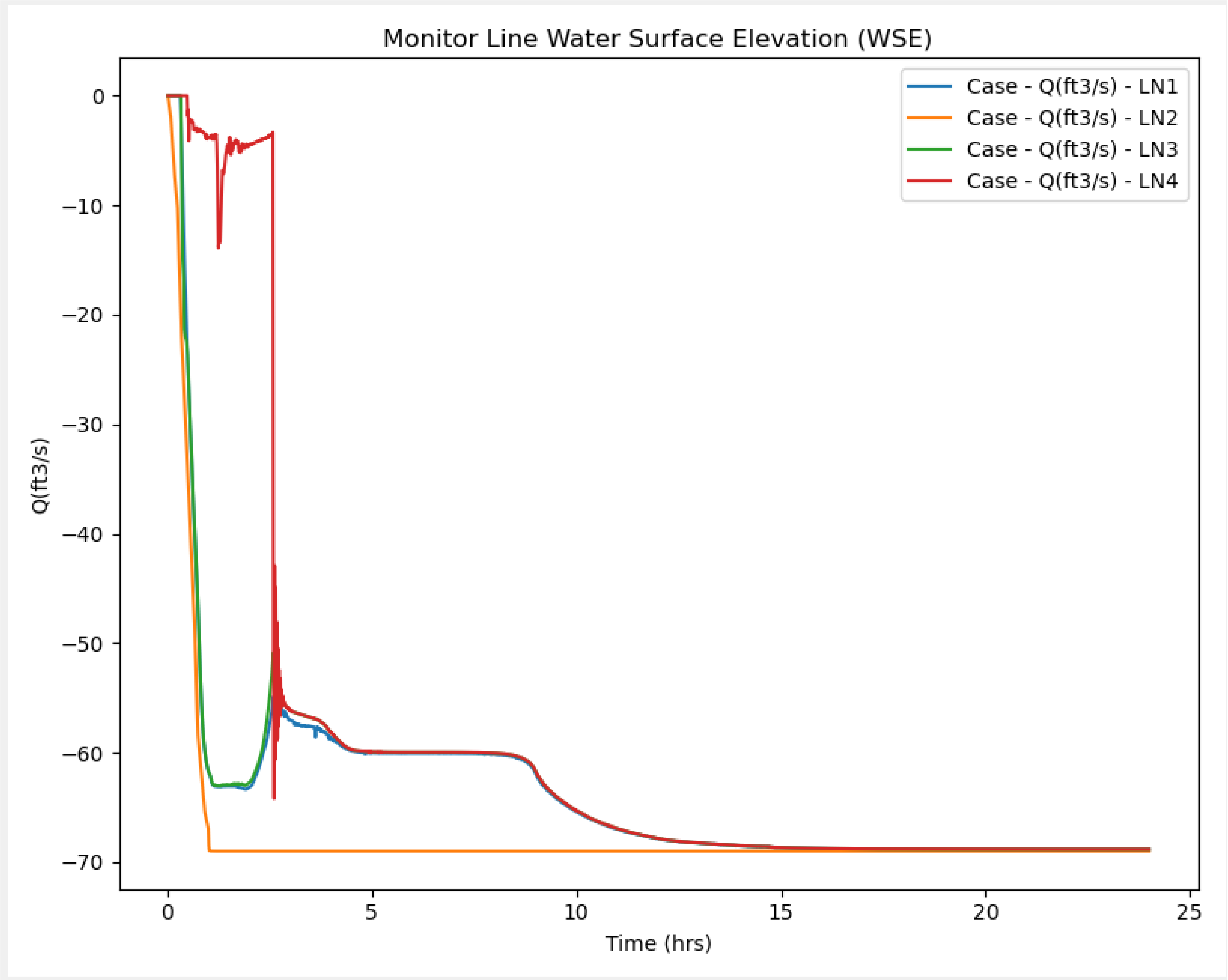


Figure I.9: Existing conditions 2-year Vance, 2-year Chehalis monitor lines

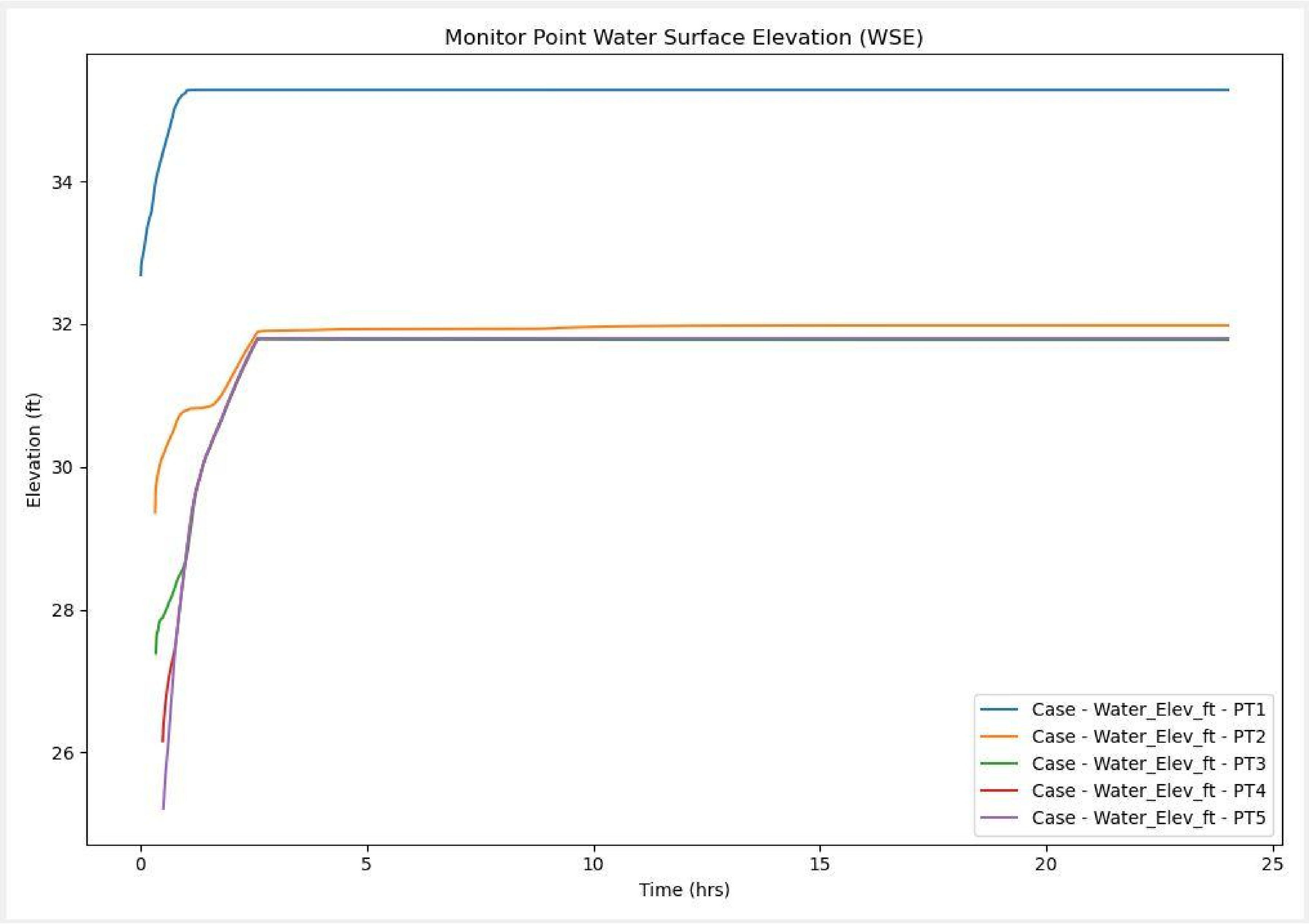


Figure I.10: Existing conditions 2-year Vance, 2-year Chehalis monitor points

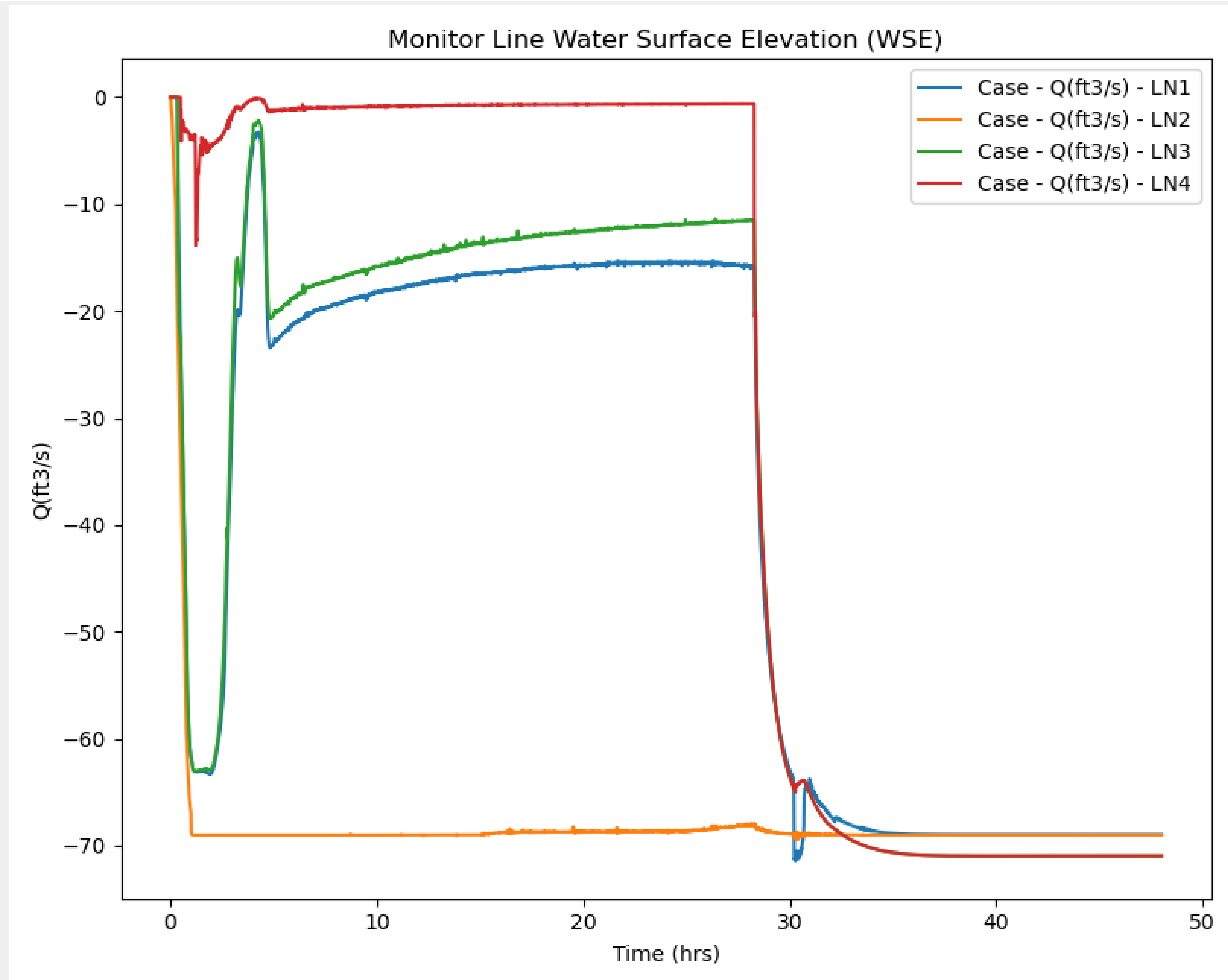


Figure I.11: Existing conditions 2-year Vance, 100-year Chehalis monitor lines

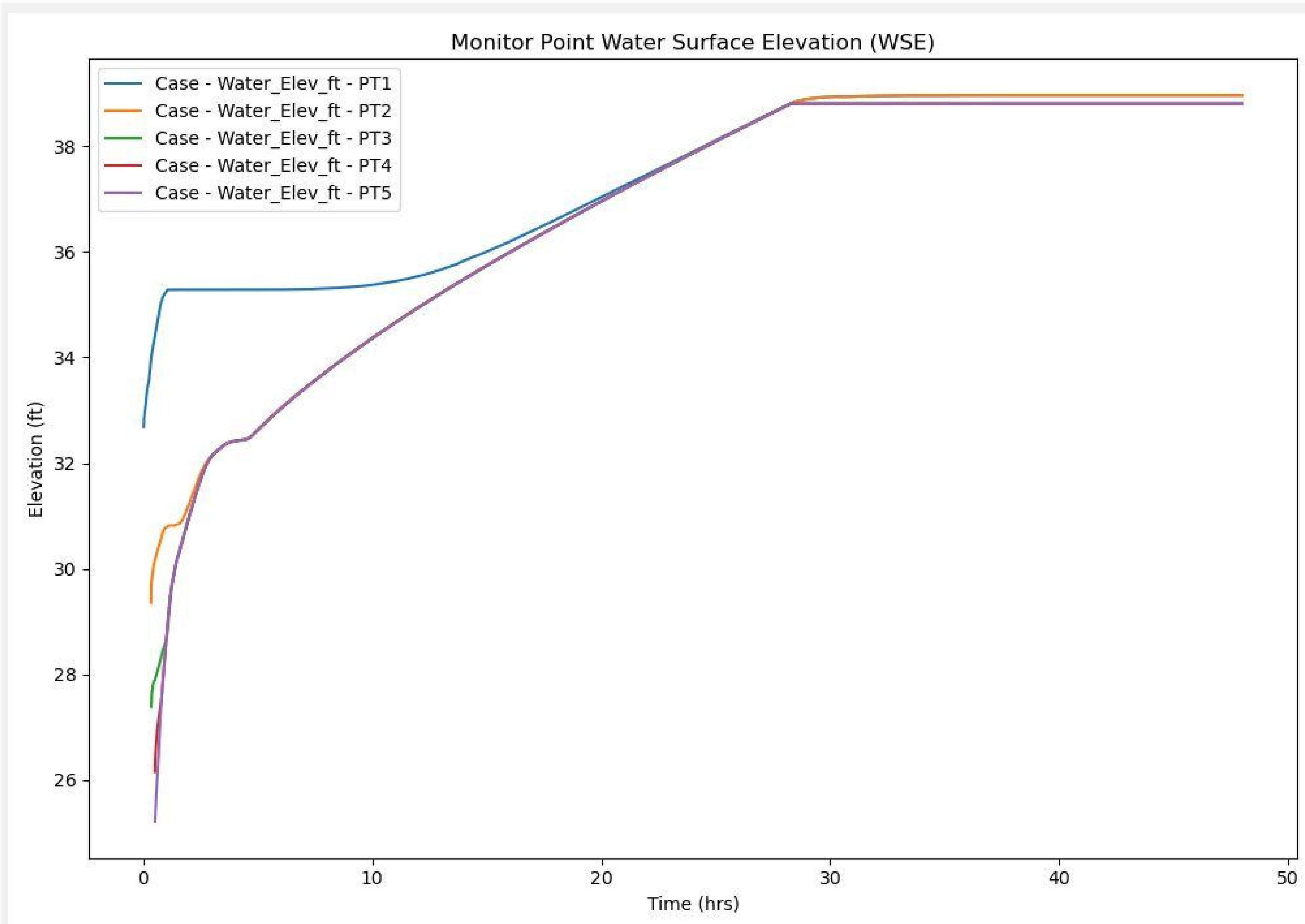


Figure I.12: Existing conditions 2-year Vance, 100-year Chehalis monitor points

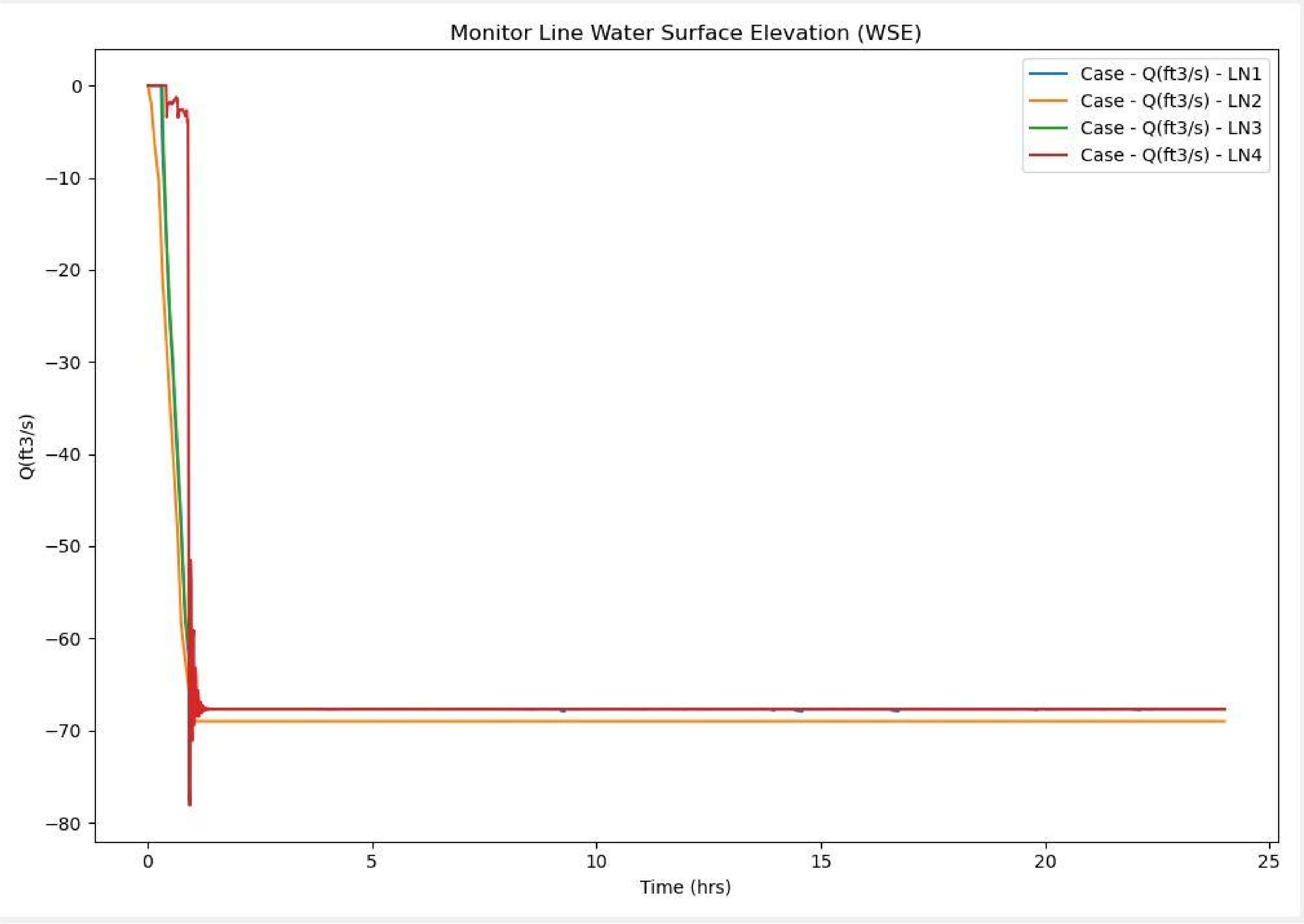


Figure I.13: Proposed conditions 2-year Vance, low flow Chehalis monitor lines

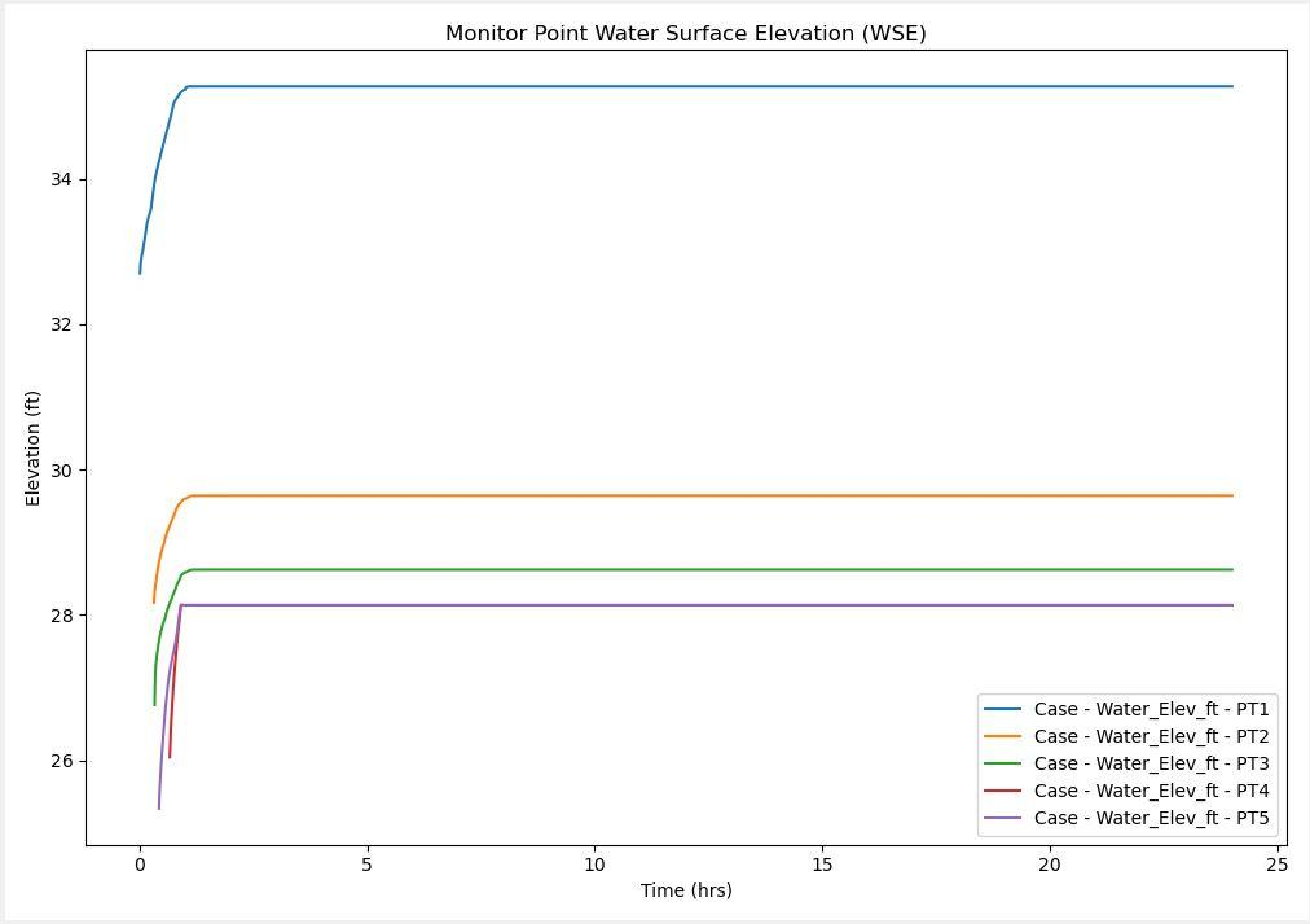


Figure I.14: Proposed conditions 2-year Vance, low flow Chehalis monitor points

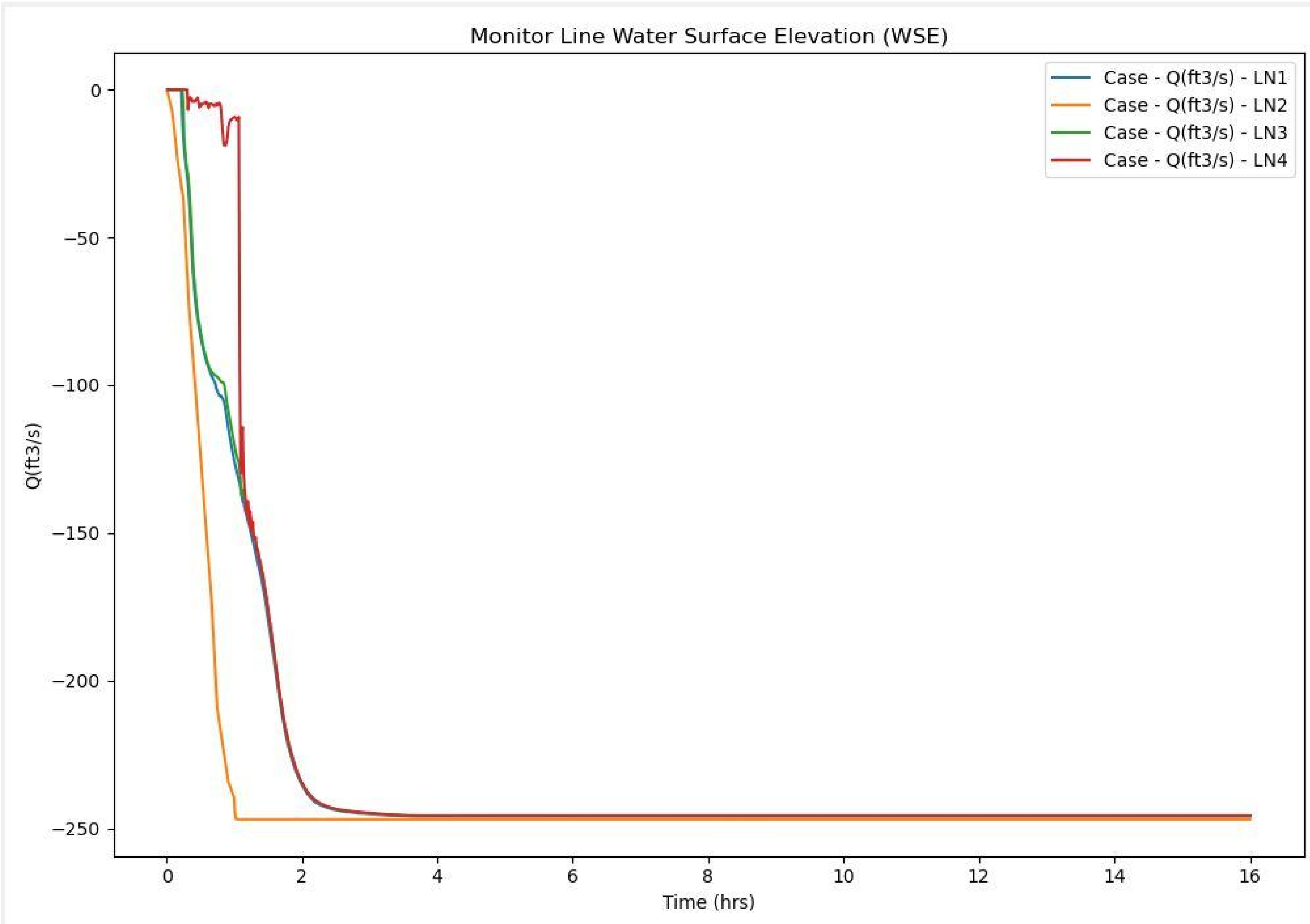


Figure I.15: Proposed conditions 100-year Vance, low flow Chehalis monitor lines

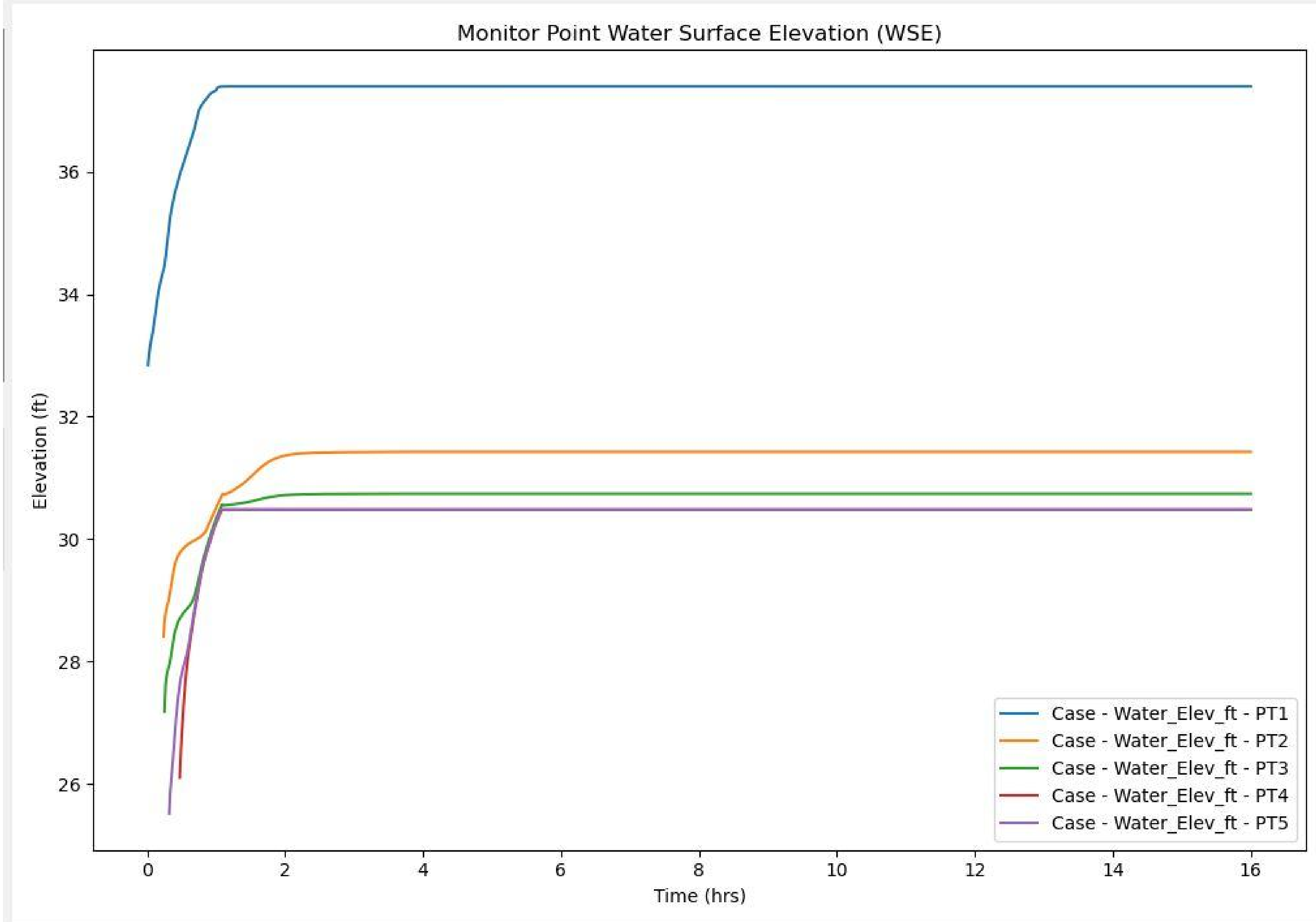


Figure I.16: Proposed conditions 100-year Vance, low flow Chehalis monitor points

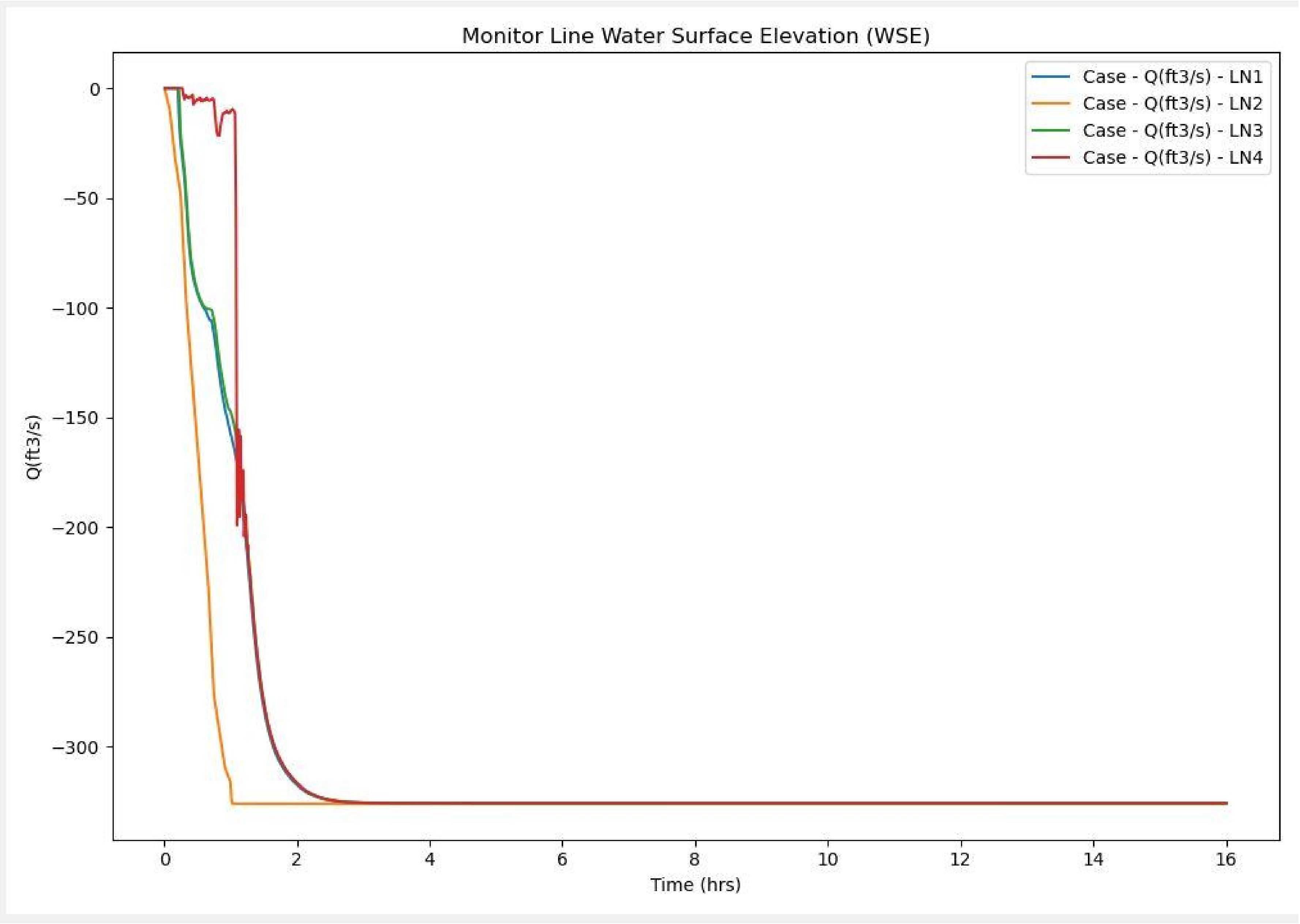


Figure I.17: Proposed conditions 500-year Vance, low flow Chehalis monitor lines

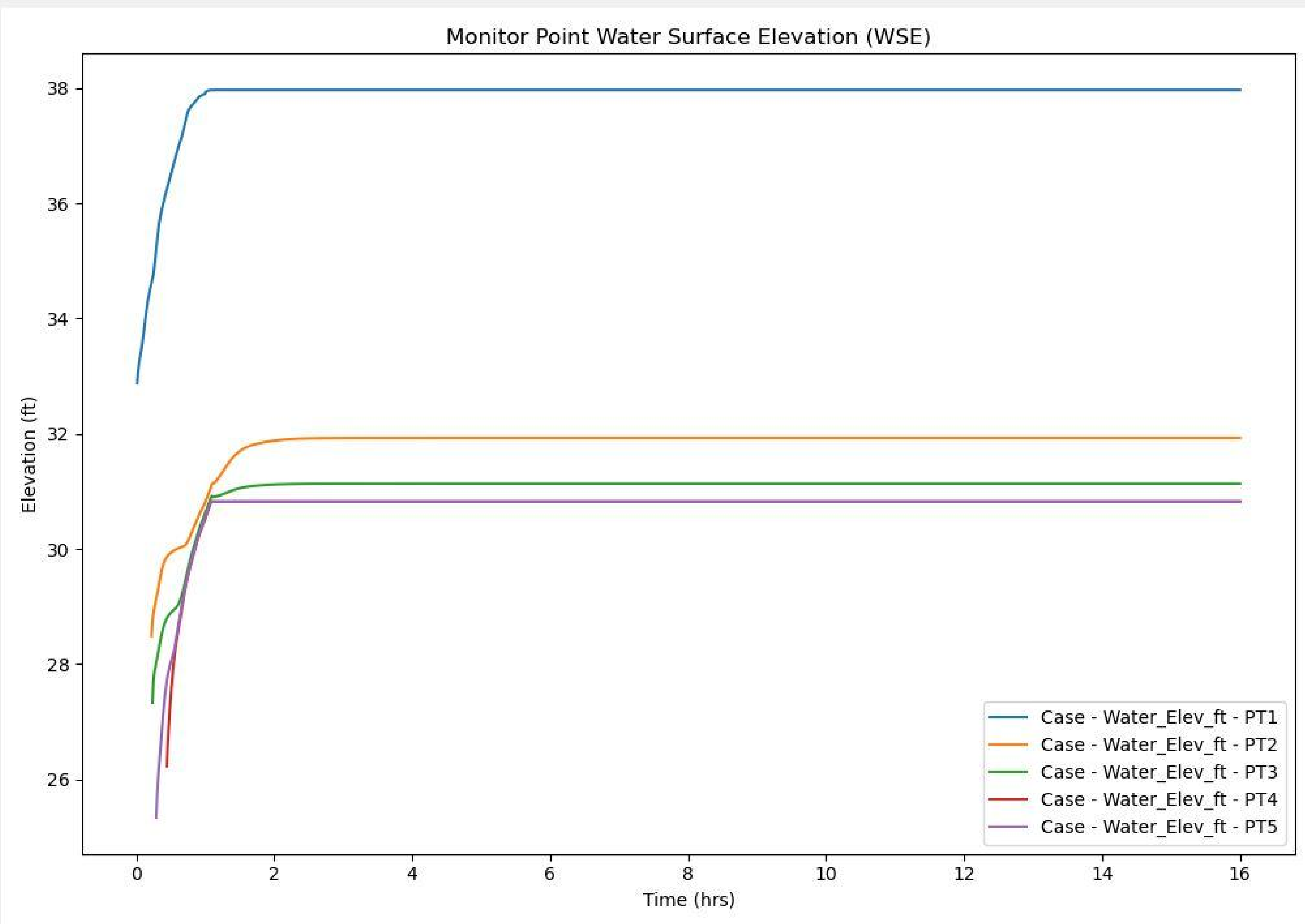


Figure I.18: Proposed conditions 500-year Vance, low flow Chehalis monitor points

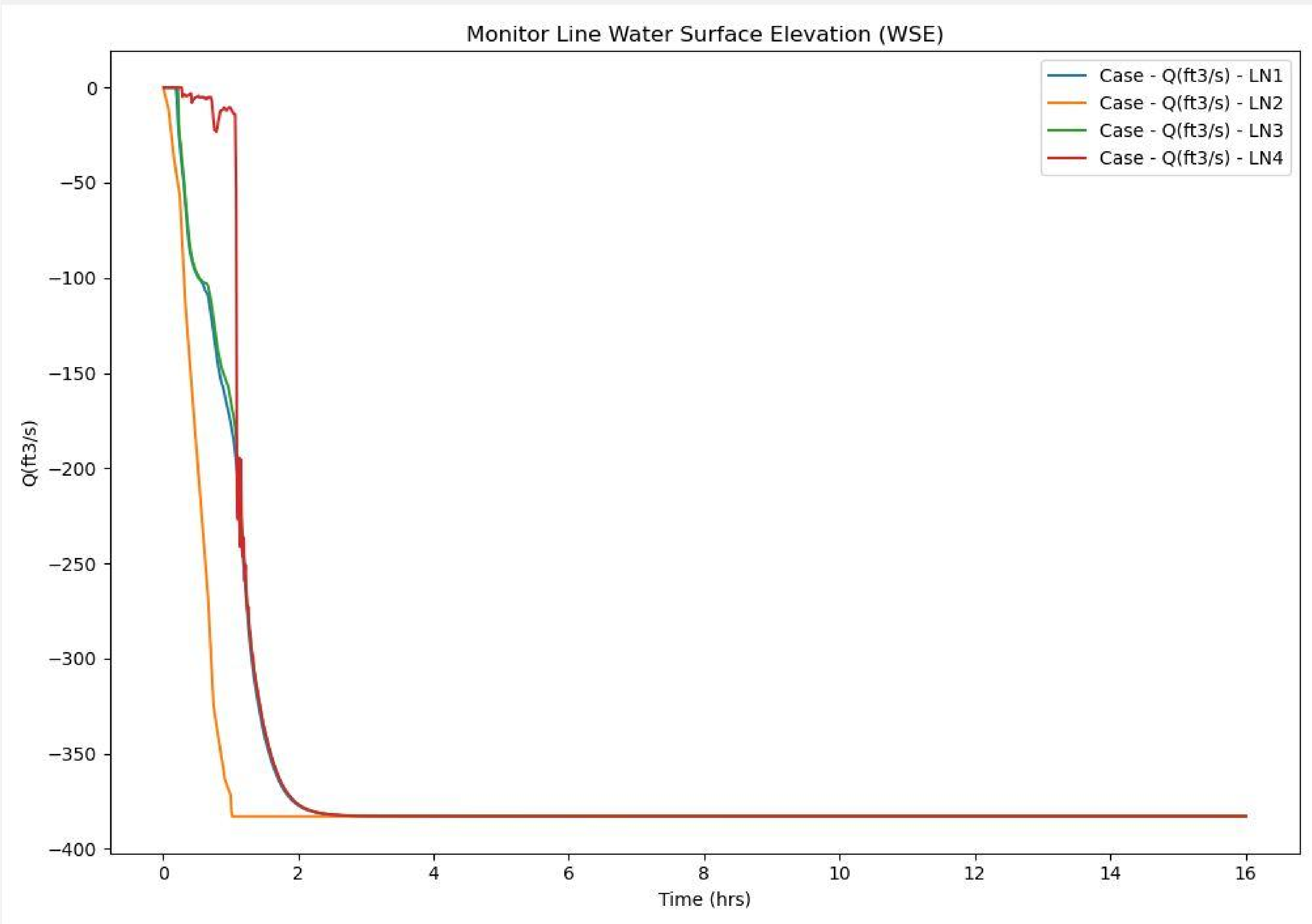


Figure I.19: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis monitor lines

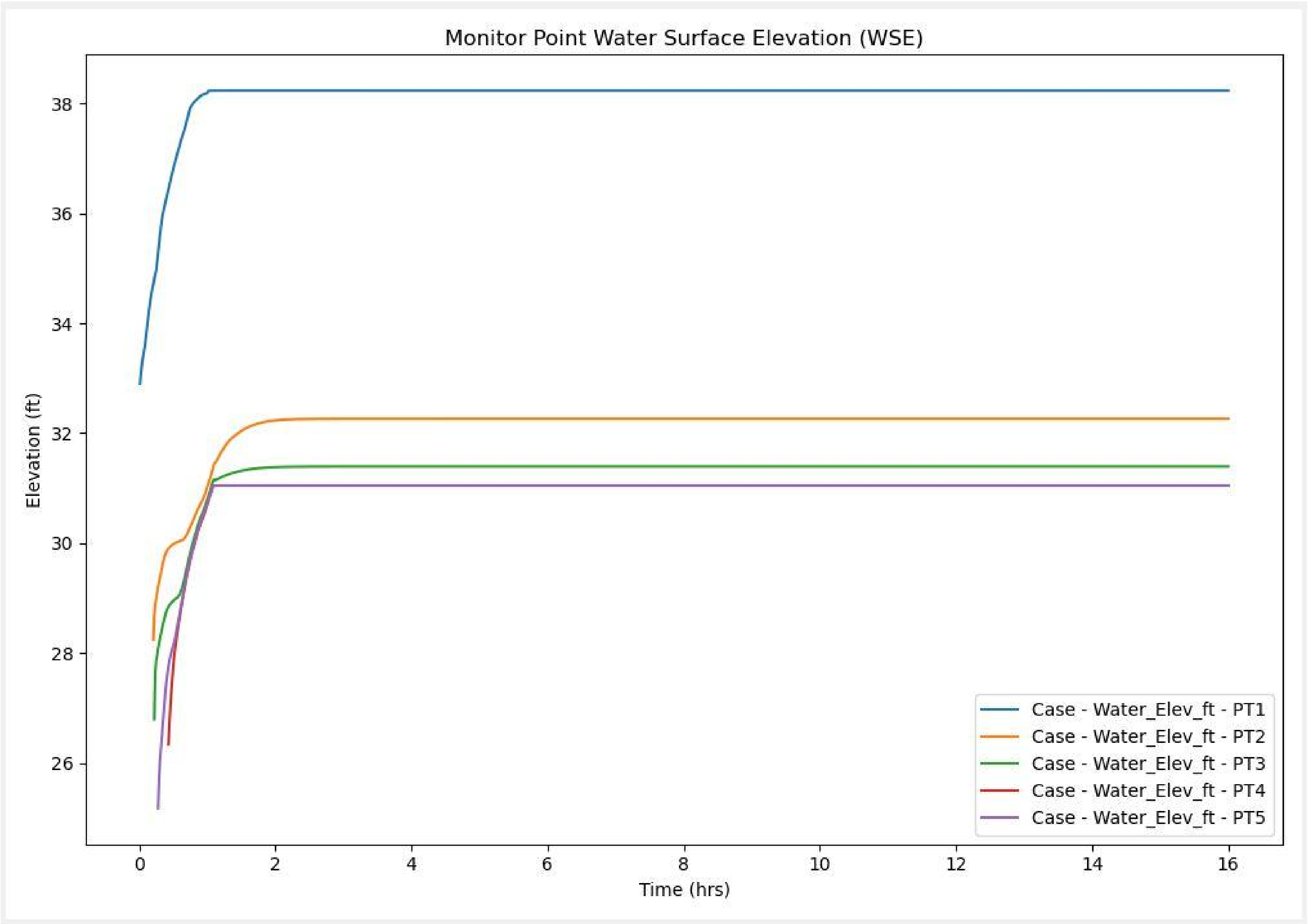


Figure I.20: Proposed conditions 2080 predicted 100-year Vance, low flow Chehalis monitor points

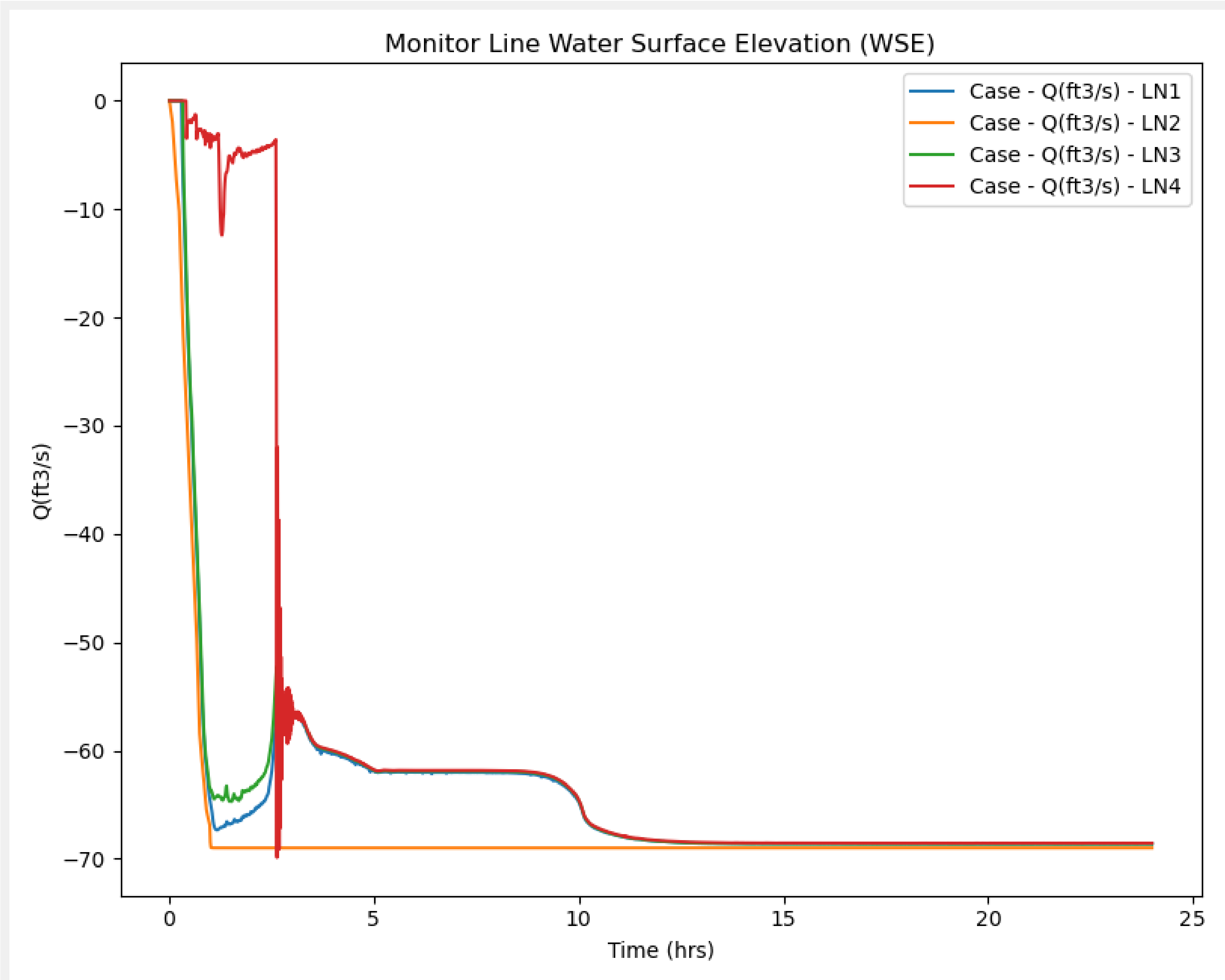


Figure I.21: Proposed conditions 2-year Vance, 2-year Chehalis monitor lines

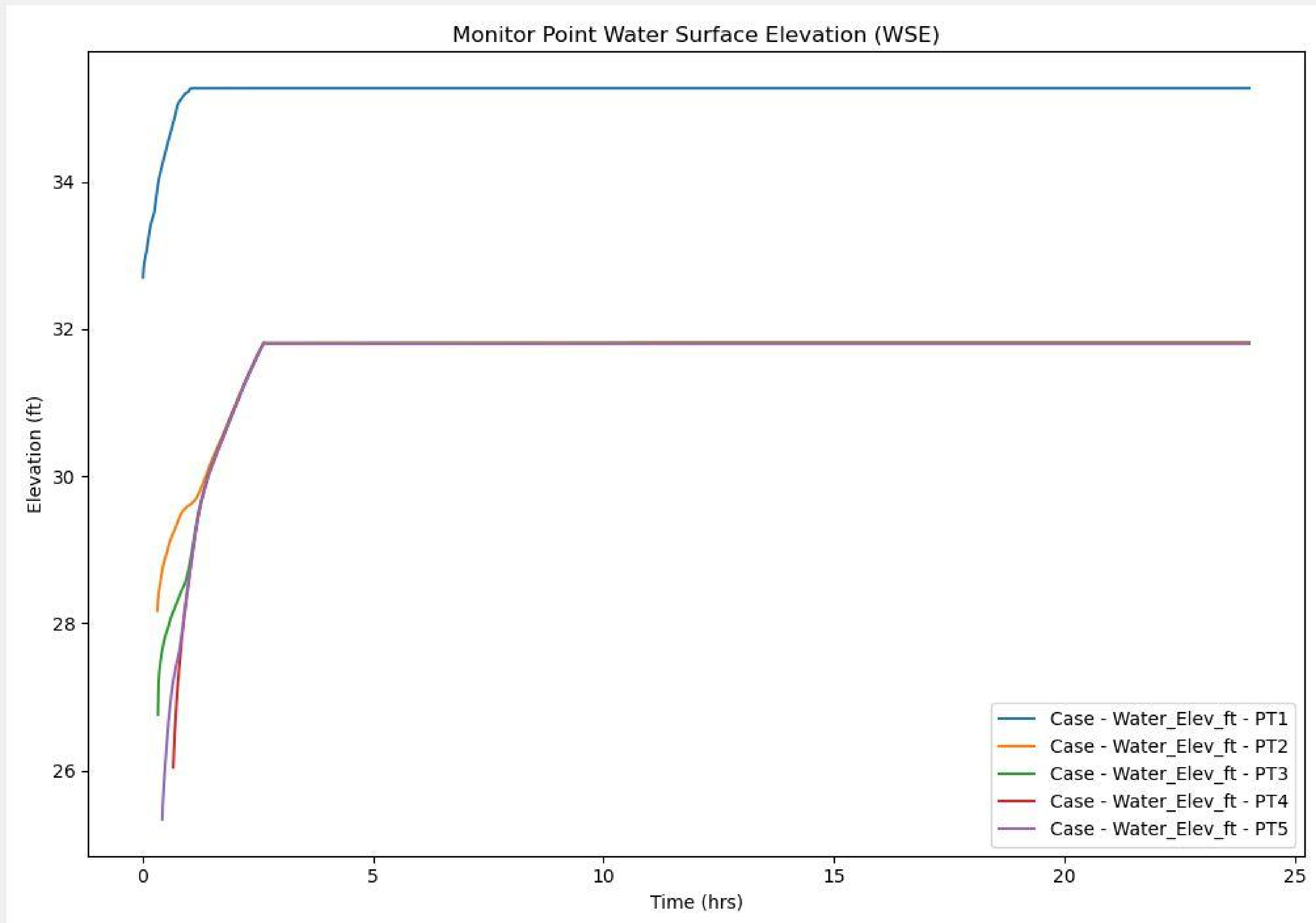


Figure I.22: Proposed conditions 2-year Vance, 2-year Chehalis monitor points

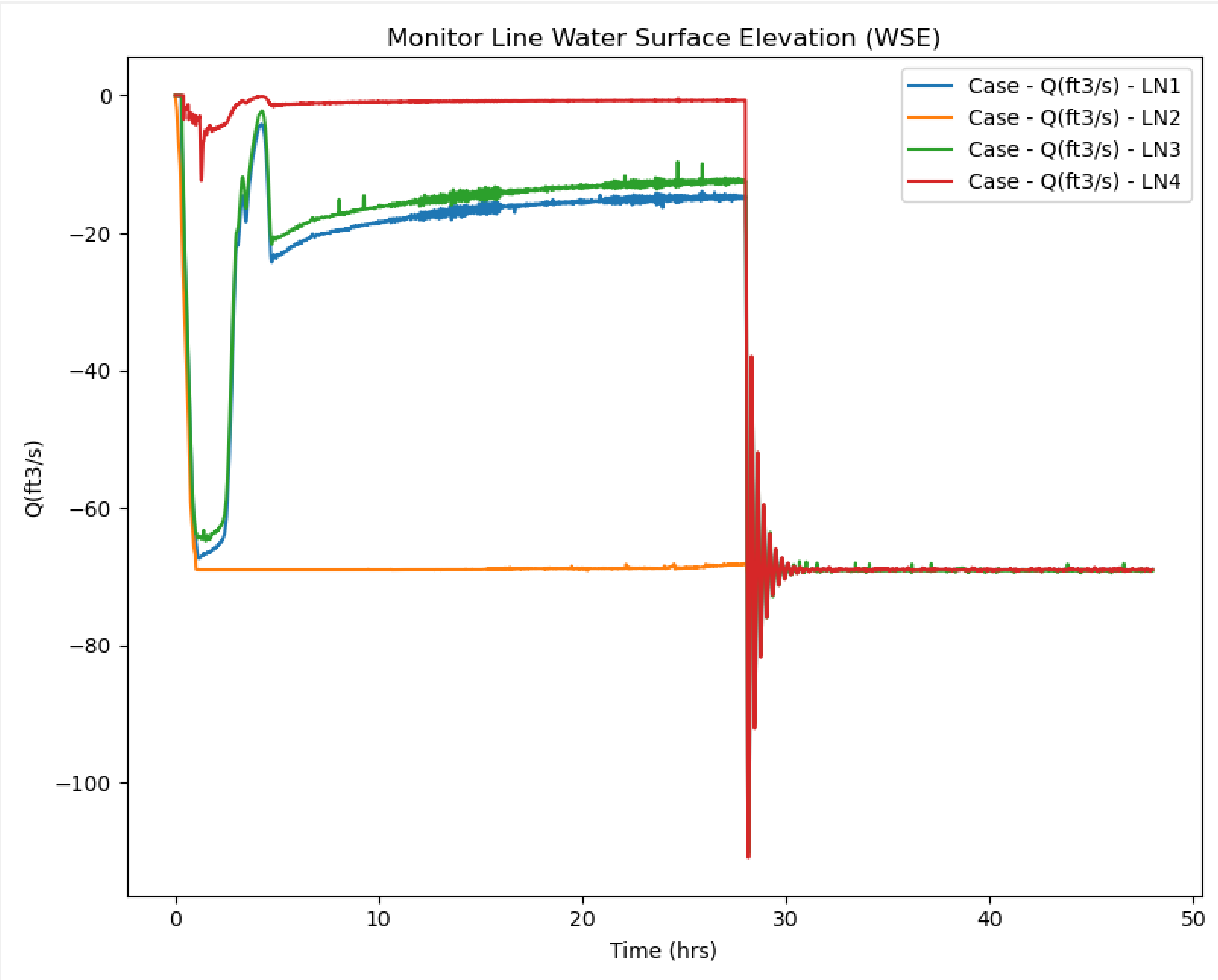


Figure I.23: Proposed conditions 2-year Vance, 100-year Chehalis monitor lines

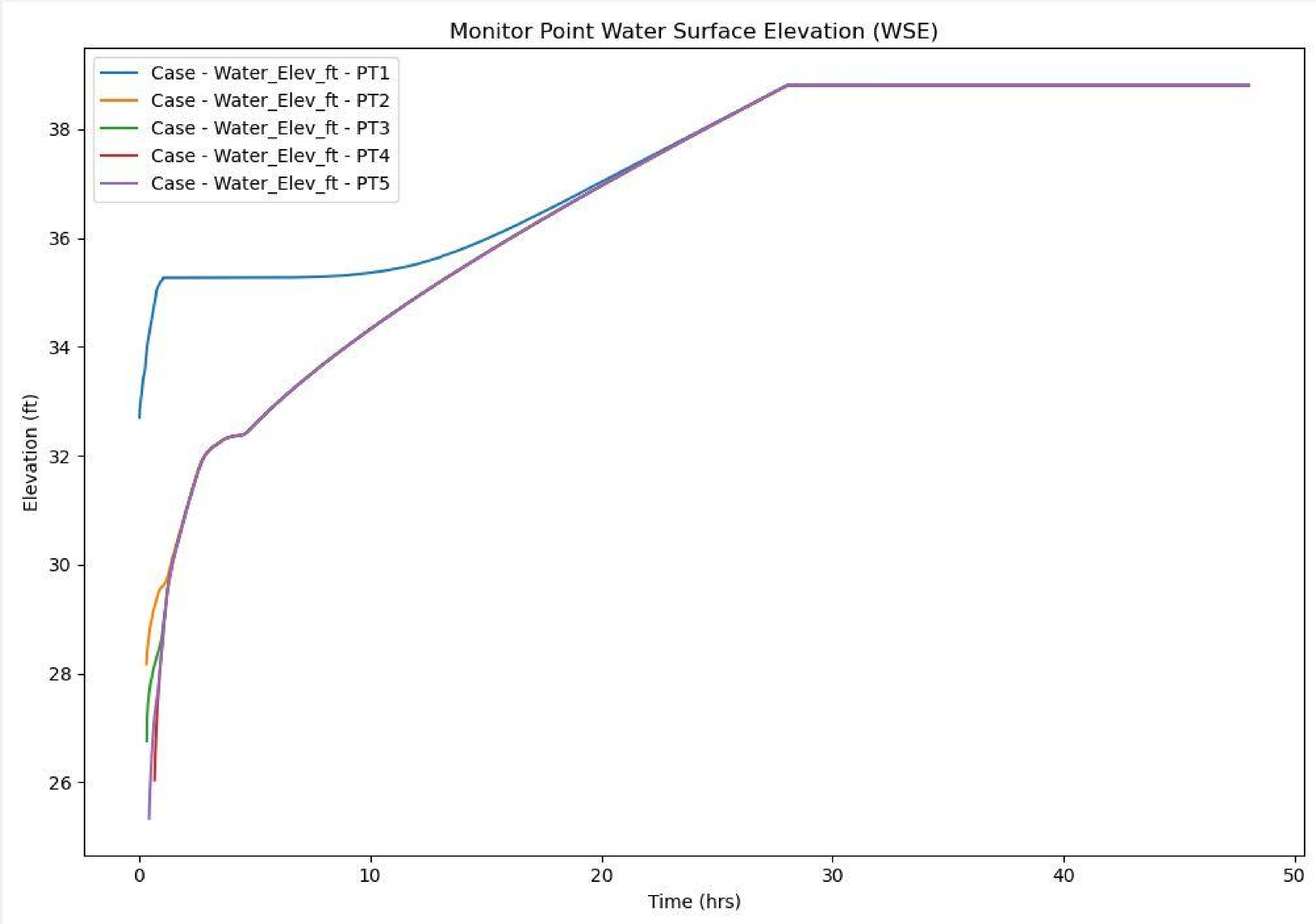


Figure I.24: Proposed conditions 2-year Vance, 100-year Chehalis monitor points

Appendix J: Reach Assessment (Not Used)

(A Reach Assessment was not conducted for this crossing)

Appendix K: Scour Calculations

(See Section 7.3 for determination of scour depth)

Scour in channel bend
Source: WDFW, App E

Thorne Equation (for gravel beds)

$d = y_1[1.07 - \log(R_c/W-2)]$ for $2 < R_c/W < 22$

input data in blue:	value =	source
y_1 = average flow depth directly upstream of the bend (ft)	1.98	from HEC RAS
W = width of flow (bankfull for high flows) (ft)	12	from HEC RAS
R_c = radius of curvature at channel centerline (ft)	160	measured from CAD

Calculated values:		value =	
	R_c/W =	13.33333	OK
maximum depth of scour below local stream bed elevation	d =	0.0	ft

Maynard Equation (for sand beds)

input data in blue:	value =	source
R_c = Centerline radius of the bend, (ft,m)	160	measured from CAD
W = Width of the channel at the bend, (ft,m)	12	from HEC RAS
A = Cross sectional area upstream of bend (ft^2, m^2)	34.52	from HEC RAS
W_u = Channel width upstream of bend, (ft,m)	12	from HEC RAS
Dm = Measured water depth in bend, (ft,m)	2	from HEC RAS

D_{mnc} = Ave water depth in the cross section upstream of bend, (ft,m) 2.9

checks for valid use of this method:

1) Rc/W should be > 1.5	Rc/W =	13.3	OK
2) Rc/W should be < 10	Rc/W =	13.3	use Toe-Depth m
3) Overbank depth should be less than 20% of main channel depth			

Computation:

$$Dmxb = Dmnc\left[1.8 - 0.051\left(\frac{Rc}{W}\right) + 0.0084\left(\frac{W}{Dmnc}\right)\right] = 3.3 \text{ feet (m)}$$

Scour Depth = 1.3 feet (m)

(Water depth at scour - Water depth w/o scour) ethod

Appendix L: Floodplain Analysis

(A Flood Risk Assessment will not be completed for this site)

Appendix M: Scour Countermeasure Calculations (Not Used)

(Traditional scour countermeasures are not used at this site.)